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"ENVIRONMENTAL PROTECTION IN OPENPIT COAL MINING"
HELD AT DENVER, COLORADO ON 27-29 MAY 1975

John Craig, et al

Denver Research Institute

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"ENVIRONMENTAL PROTECTION OF OPENPIT COAL MINES"

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September 1975

FORWARD

For the past three years the Environmental Protection Agency has conducted an extensive research program with the Central Research and Design Institute for Opencast Mining, "POLTEGOR," Wroclaw, Poland. This research is important to the energy and environmental requirements of the Polish Peoples Republic and the United States. To accelerate it, the two governments sponsored a joint Symposium on "The Environmental Effects of Open Pit Coal Mining," in Denver, Colorado, May 27 to 29, 1975.

With its extensive coal reserves and rapidly increasing production, Poland has developed a high level of expertise in mining technologies. The POLTEGOR Institute, with clients worldwide, represents Poland's surface mining and land reclamation expertise. POLTEGOR is conducting for EPA five mining-related projects valued at approximately \$1.4 million. These projects include studies of mining technologies, overburden and fly ash disposal, reclamation of surface mined lands, ground water protection, and mine waste by-product utilization.

EPA recognized that development of coal resources in the Great Northern Plains of the United States could benefit from Polish expertise in strip mining, water quality protection and residual waste management. The Symposium highlighted these shared problems. The Symposium also gave Polish scientists and engineers a chance to meet and to exchange experiences with their counterparts in U.S. government, industry and the academic community. In addition to EPA, U.S. government representatives from the Department of Interior, Federal Energy Administration, Energy Research and Development Administration and the Appalachian Regional Commission participated in the Symposium. The Consolidated Coal Company was the principal U.S. industrial representative. Academic representatives from the Montana School of Mines, the Virginia Polytechnic Institute, as well as the University of Denver Research Institute, actively participated in the Symposium.

We congratulate the Symposium's Directors, Mr. Jacek Libicki, POLTEGOR, and Mr. John Craig, University of Denver Research Institute, for a very successful meeting. Technical papers from the Symposium, chiefly those by Mr. Zdzislaw Zajac, President, Lignite Mines Corporation, and Mr. Henryk Turala, General Director, POLTEGOR, clearly illustrate the growing need for expanded production in both countries. These papers, plus those by the other authors, show that our two nations should be able to exploit coal reserves in a carefully planned and environmentally acceptable manner.

FITZHUGH GREEN
Associate Administrator
Environmental Protection Agency
UNITED STATES

BENON STRANZ
Vice Minister
Ministry of Mining and Power
POLAND

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INTRODUCTION - REMARKS

Henryk F. Turaża
"POLTEGOR"
General Director

The world energy and raw materials crisis, on one hand, and a requirement to give more attention to environmental protection problems, on the other, force an entirely different view of the whole matter of mining activity from the one held only a few years ago.

A significant rise in crude oil prices and the lag in expected progress in atomic power production development, and along with a wish to secure one's self-sufficiency in power resources, oblige many countries to review their thinking regarding the role of coal and other minerals as a power plant fuel. Simultaneously, the growing world demand for other minerals and the increase in their prices have made us revise our views toward the technical-economic possibilities of their extraction.

In the light of this situation, the problems of mining industry development have become extremely acute and important in many countries.

Owing, however, to the great difficulty of work in underground mines and their long construction times, and considering also the development of new techniques in manufacturing very large mining and transport machines, opencast mining is assuming a new and major importance.

Despite the many advantages of opencast mining, one negative aspect exists. This is the transformation of a natural environment -- the land's surface and the layers located near to the surface of the earth's crust, where changes have both a quantitative and a qualitative character.

In Poland, the quantity of extracted material from opencast mines doubles every 10 years, which poses very serious problems for the management and administrative authorities of the state. To assure the most suitable technical-economic solutions to the exploitation problem and environmental protection, all research and design work in opencast mining has been concentrated in the hands of the Central Research and Design Institute for Opencast Mining, "Poltegor," in Wrocław.

These activities concern all the areas connected with opencast mining of all minerals, and all phases of that mining activity, starting with geological prospecting, exploitation and transport technology, and environmental protection. More than 1200 persons are engaged in solving these problems in our Institute, and, of this number, about 600 are engineers, 40 are PhD's, and 11 are professors. Such a concentration of specialists gives us substantial competence to achieve high level technical solutions. Aside from the work carried out on assignment for the Polish mining industry, we also undertake many jobs carried out for other countries in Europe, and also for countries outside of Europe.

In the last two years, our cooperation with the United States has developed strongly, and in particular with the Environmental Protection Agency, in the sphere of environmental protection in open pit mining. Therefore, we welcomed with great pleasure the proposal for organizing today's meeting-symposium which will allow a large-scale exchange of opinions and information and will most certainly aid in the solution of these essential problems in our countries. I am quite convinced that with the employment of suitable mining methods and techniques for environmental protection, the negative influence of open pit mining on the environment cannot only be limited, but in many cases can be a factor in shaping the environment in a direction useful and desirable to society.

OPENPIT MINING OF LIGNITE IN POLAND

Zdzisław Zajac
President
Lignite Mines Corporation

Introduction

The world production of all raw materials for the power industry from primary sources, such as hard coal, lignite, crude oil, natural gas, electric energy from hydro-power stations, atomic and geothermal stations attained in 1973 equals, in terms of hard coal, 7920 million tons. Utilized in the calculations were the statistical data contained in the "World Energy Supplies, 1968-71" U.N.O. Report, New York, 1973. Conversion factors for one ton of lignite in Czechoslovakia and in France correspond to 0.6 for Poland and Italy, and for the Soviet Union to 0.5, for the remaining countries 0.3 tons of hard coal as its equivalent. As a comparison, one ton of crude oil corresponds to 1.3 tons of hard coal, 1000 m³ of natural gas is equivalent to 1.33 tons, and 1000 KW/h equals to 0.125 ton of hard coal.

The real worldwide extraction of hard coal in 1973 was 2155 million tons, crude oil 2675 million tons, natural gas 1245 billions m³, and lignite 816 million tons.

Poland's share in the production of power industry raw materials was 177 million tons, representing 2.2 percent of the world total. Of this, hard coal plays the greatest role achieving 157.0 million tons, or 7.3 percent of the world production -- actually fourth place in the world. Production of lignite for the same period came up to 39.2 million tons, i.e., 4.8 percent of the total world production of this raw material, and with this production, Poland actually occupied fifth place among the nations producing lignite, preceded only by East Germany, the Soviet Union, West Germany, and Czechoslovakia.

Before World War II, lignite was not very popular as a fuel. Its extraction was concentrated chiefly in Central Europe, mainly in Germany, which produced 80 percent of the world's supply.

After World War II, with the world shortage especially in Europe, of raw materials for the power industry, a greatly increased interest in lignite as a complementary basic fuel emerged -- a role that until then was held by hard coal.

Under the pressure and necessity for significant and rapid increases in extraction, a program was launched to construct modern machinery with large output, to facilitate and accelerate openpit exploitation. Marked progress also has taken place in the technology of the movement, and stacking of large masses of materials, and in techniques of draining, reclamation, and auxiliary work mechanization. The economic advantages gained through openpit technology,

especially in the light of the changing economic situation in relation to the prices for crude oil, augur for it a further tendency toward development.

To support this proposition one can consider Poland as an example.

In the period between the two World Wars, Poland with regard to lignite exploitation did not exist in the world statistics, and its significance in the national economy was negligible. Small primitive mines were being shut, one after another, as a result of exhaustion of existing resources. The period of economic depression did not encourage further prospecting or exploitation. And because of the slowly growing requirements of the power industry and the monopoly of hard coal during the thirties, industrial exploitation of lignite was not considered as profitable. In the years 1920-1938, its exploitation decreased from 270 to 20 thousand tons annually.

The needs of the rapidly developing Polish economy after World War II imposed the necessity of prospecting for relatively cheap, easily accessible and abundant sources of prime energy. The lack of resources of crude oil and natural gas and the small possibility of hydropower utilization focussed particular attention on lignite which, as a raw material for large power units, could compete with hard coal. Faster development of underground mining of hard coal -- which, in addition to being a valuable export item, was also indispensable as a coking raw material -- was for various reasons impeded.

Facing an energy shortage situation, a decision was taken in 1956 to develop lignite openpit mining as the source of fuel for big power plants. The following propositions favored this development:

- The possibility of a wholly mechanized exploitation process enabling the attainment of high productivity per employee.
- A comparatively short cycle of construction to extraction, i.e., a short period for investment return.
- Greater safety and better working conditions in openpit mines than in underground mines.
- Lower cost of extraction as calculated in terms of standard B.t.u. fuel, in comparison to other power industry raw materials.

Intensive geological prospecting enabled us to discover new lignite deposits and to construct new open pits.

This dynamic development led to a quantity of extracted lignite of about 40.0 million tons and of removed overburden to 128 mil m³ occurring in the seventies.

Both the existing mines and the ones under construction are subordinated to the Lignite Mines Corporation located in Wrocław.

All the research and project work for this area of the coal industry and also for the openpit mining of other minerals is controlled from Wrocław by the Central Research and Design Institute for the Opencast Mining, "Poltegor," which cooperates on a broad basis with other countries, i.e., with E.P.A.

The Geological Conditions of the Polish Lignite Deposits

Polish lignite deposits of industrial significance occur mainly in southwestern and central Poland, and are of the Tertiary period, and more exactly of the Miocene age. They are characterized by -- depending on the region of occurrence -- a marked diversification in their geological structure. Such a diversification expresses itself both in the different geometry of the deposits and in a different lithology and tectonics. Owing, however, to their difference

from American conditions and the necessity to use different mining techniques, a description of our situation is necessary.

In the Turów region (Figure 1), lignite occurs in the form of two main seams with a thickness of 20-40 m each, and a third bed in the shape of several thin benches with lignite of thicknesses 2-10 m, occurring in the overburden. The overburden and the band layers between the seams are composed of 80 percent clays and about 20 percent sands formed in the shape of closed lenses. The deposit is formed in an outline of a basin causing an increase in the thickness of the overburden from 30-70 m on its edges to over 200 m in its center. The layers underlying the bottom seam constitute, similarly as in the overburden, Tertiary clays.

In the region of Konin and Adamów (Figure 2), there is only one seam of lignite with a thickness of 10-15 m deposited horizontally, covered with an overburden 40-50 m thick. The overburden is clays, containing sand lenses constituting about 20 percent of its thickness. The lignite seam underlies a layer of water saturated sands that are several meters thick.

In the region of Bełchatów (Figure 3) where a new mine is being constructed, the seam of lignite is 50-100 m thick, covered with a 20 percent clay and 80 percent sand overburden 100-200 m thick.

Lignites petrographically belong to soft coals with a significant humidity content, about 50 percent, and a certain admixture of xylites.

The caloric value fluctuates from 1700 to 2400 k.cal/kg, with a low sulphur content, 0.5-1.0 percent, and low ash from 6-20 percent.

The industrial ratio of the overburden versus lignite fluctuates within the 2 m³/1 t-9 m³/1 t limits and offers conditions for economic exploitation.

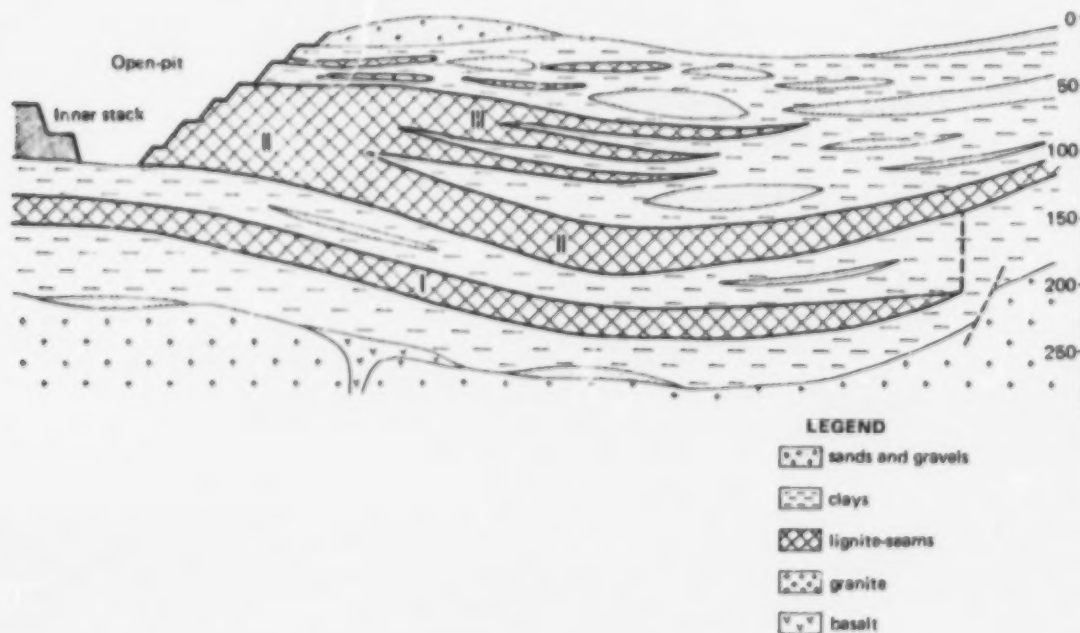


Figure 1. Schematic N-S Section of Turów Lignite Basin.

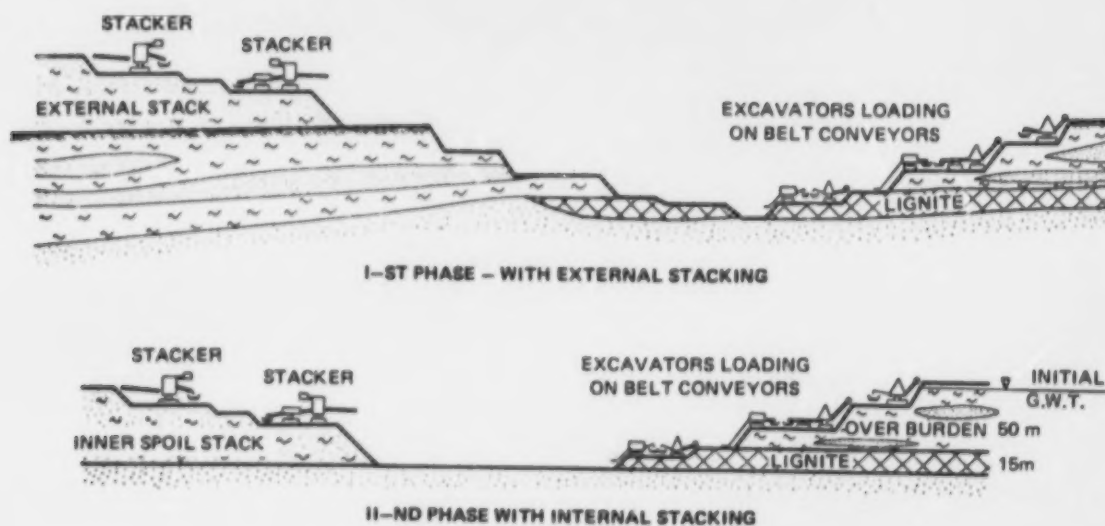


Figure 2. Scheme of Lignite Extraction in the Konin Basin.

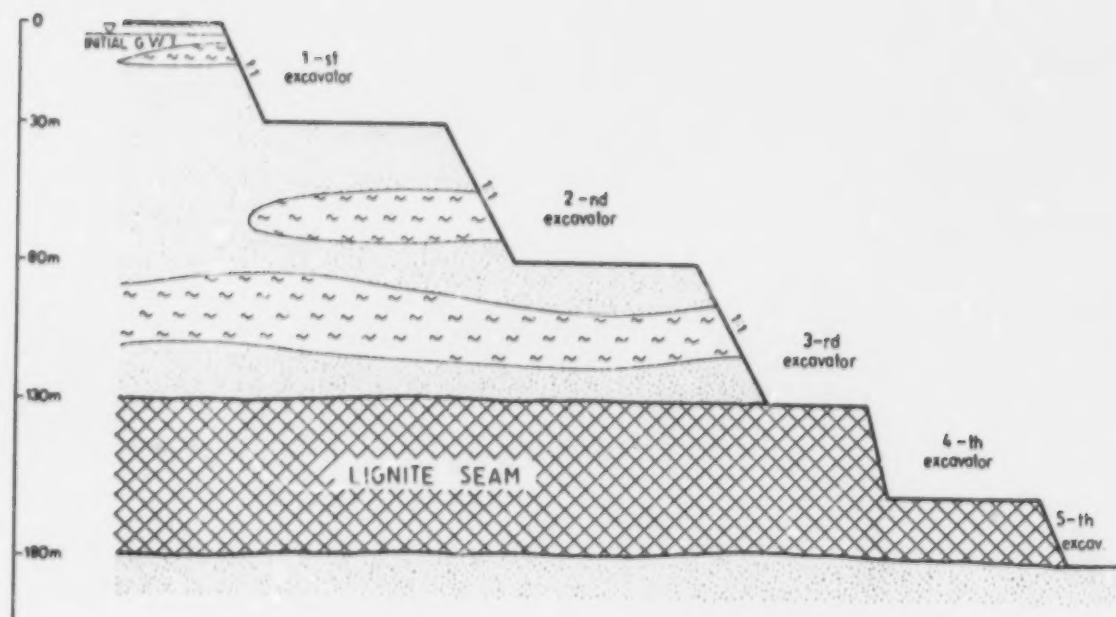


Figure 3. Schematic Longitudinal Section of Lignite Extraction in Bełchatów Basin.

In the deposits described above are working:

- One open pit with an output of about 22 million tons of lignite annually.
- Four open pits with a production of 3-5 million tons of lignite annually each.

Under construction is an open pit with a planned production of 40 million tons of lignite per year, and on the drawing boards are two other open pits with outputs each of 25 million tons of lignite annually.

Hydrogeological Conditions and Drainage Problems

All the lignite deposits in Poland are situated in conditions of strong waterlogging. The initial ground water table occurs everywhere at a depth of from 0 to 5 meters below the terrain's surface.

Depending on the local conditions, waters are the free water table or subartesian water table waters. In the overburden of the pits in the Turów and Konin regions, the dominant waters are in closed lenses characterized by pressures dependent on the depth, and which fluctuate from 1 to 20 atmospheres. The sands underlying the lignite bed in the Konin region have waters under a pressure of up to 6 atmospheres, and the spreading of this horizon is practically unlimited. Sands in the Bełchatów area, which compose the overburden and underlie the coal bed, are saturated with water coming from the surface of the terrain to the full depth, i.e., to about 300 m.

To permit mining, a deep draining system is build approximately two years in advance of the mining operation to draw down the ground water table to below the bed floor level. The depth of this water lowering ranges from 50 to 300 m, and is being achieved with the aid of batteries of wells equipped with submersible pumps, or galleries with draining holes. The quantities of water inflow to particular pits fluctuate within 30 to 300 m³/min. per pit, and the range of the depression cones made by these draw-downs reaches 10 and more kilometers.

The Technology of Exploitation

With depths of exploitation ranging from 60 to 250 m from the terrain surface, there is the necessity to divide the mined layers of overburden and lignite into extracting levels. The height of these slopes depends on the lithology of the rocks and on the particular excavating machines used.

In the existing pits, the heights come to 10-24 m for the overburden and 5-15 m for the lignite seam. But in the openpit mine, Bełchatow, now under construction, these values for the overburden are 50 m and for the lignite 30 m.

Depending on the method of working on the levels, the long wall system of working is employed with the excavator shifting along the whole wall of the excavated slope, or a short wall system (pillar) based on the excavation of a recess (cavity) to a 20-50 m depth perpendicular to the shifted slope.

The first method is used for chain excavators with running gears on rails, and the second method for the bucket wheel excavators and chain excavators with the caterpillar running. This last system is used in the prevailing number of open pits and levels.

Depending upon the progress of exploiting faces and levels, we distinguish systems: a parallel and a fanlike.

Depending upon the occurrence of the lignite, one uses different technological systems for the removal of overburden only, of mineral only, or overburden-coal-mixed systems. The latter require a selective working of the coal when, in the range of one excavator, both the spoil and the lignite exist. In the transportation of the overburden or the lignite, one employs cyclic road-rail systems and systems with the continuous belt-conveyor transportation.

Belt conveyor transport systems are now replacing rail transport in our pits.

The stacking of overburden in the initial phase of exploitation is on the outside of the open pit and, later on, only in the inside of the pit.

Technological systems called the E-T-S systems (excavator-transporter-stacker) by us can be monoblock (single) or complex systems, in which several excavators provide for one or more transporting lines, subordinate to one or more stackers. Parallel monoblock systems, and complex E-T-S systems, as a rule, possess reversal stations, allowing any optional excavators to be mixed with any stackers.

The lignite deposits, to be put into production in the near future, are characterized by an increased depth of deposition (140-250 m) and will require new directions in mining technology. An essential direction in modifications is the adoption, exclusively, of a belt conveyor transport and monoblock system in the overburden and lignite, working with a simultaneous balancing of the output of the whole E-T-S system. The second essential direction is toward the increase in the heights of particular slopes, permitting the reduction in the number of machines and transportation lines and the achievement of maximum output concentration.

The Polish openpit lignite mines can be classified according to three technological models:

- I model - exploitation with fanwise slope progress and a rail transport system (open pits Gosławice and Patnów);
- II model - fanwise progress of extraction with the prevailing belt conveyor transportation: transport of the lignite onto the surface by inclined lifts (open pits Adamów, Turów); and
- III model - parallel progress of the face, with the cut situated on one of the deposit's edge with belt conveyor and transportation of the lignite through the movement from time to time of the ramps (open pits Kazimierz, Józwin, Bełchatów, Szczerców).

Excavating, Transporting and Stacking

The equipping of the Polish lignite open pits with excavating machinery consists exclusively of bucket wheel excavators running on caterpillar undercarriages, and of chain excavators working on rail running gears.

As regards the scope of excavation, the machines are being adopted to the undershot work (mainly by the chain excavators) and to the overshot work (as a rule by the wheel machines).

Presently, in our strip mines we employ excavators of outputs ranging from 700-3450 m³/hour. The quantities and types of excavators used were subject to the technology and, also, partly to the production capacity of the manufacturer of such equipment. Characterization of the utilized excavators and stackers is illustrated by Table 1.

Table 1. Specification of basic machine types used in the lignite industry and their characteristics

Characterization type of excavators and stackers	Wheel Excavator SRs 1200	Wheel Excavator Sch Rs 1200	Wheel Excavator Sch Rs 800	Wheel Excavator Sch Rs 315	Chain Excavator D- 1120	Chain Excavator Rs 560	Chain Excavator Rs 410	Chain Stacker ARSB- 8800	Chain Stacker ARSB- 5800	Chain Stacker As 1120
Theoretical output m ³ /h	3,450	2,150	1,680	1,080	1,920	700	1,400	8,800	5,500	1,920
Elementary digging power kg/cm	110	60	50	40	-	45	75	-	-	-
Working height top cut	24	22	20	12	-	15	17	-	-	-
Working height bottom cut	4	2	-	-	24	17.5	17	-	-	-
Service weight T	1,418	1,900	1,230	347	1,320	950	960	3,750	1,600	1,135
Elementary sub- soil load kg/m ²	1.04	-	-	-	-	1.3	1.1	1.05	1.05	-
Diameter of the working wheel m.	12.2	8.2	7.5	6.3	-	-	-	-	-	-
Capacity of the digging bucket dm ³	1,200	1,200	800	315	1,120	-	-	-	-	1,170
Height of the top cut stacking	-	-	-	-	-	-	-	45	31	18
Block width of stacking m	-	-	-	-	-	-	-	138/129	80/80	40/40

Note: Excavator D-1120 and stacker As 1120 have a rail undercarriage. The remaining types of excavators and stackers have caterpillar undercarriages.

A fundamental output capacity of our open pits is based on 25 overburden excavators in 4 types, 11 stackers in 3 types, and 9 lignite excavators in 3 types.

The above mentioned machines represent the so-called first generation of openpit machines used in the Polish lignite strip mines with an output capacity from 6,000-40,000 m³/daily.

In the strip mines under construction, Bełchatów and Szczerców, machines of the second generation will be used with an output of 110,000 m³/daily, and in the "drawing board" technology of the Legnica deposit exploitation, the use of third generation machines with an output of up to 200,000 m³/daily is being considered.

The number of machines, with a three-fold capacity increase in lignite output, will in the near future amount to 90 pieces, and the length of the conveyor belts will grow from the present one of 120 km to one of 400 km.

Progress in the construction of the stackers is also evident. Their efficiency grew from 1,200 m³/h to 8,800 m³ in the present strip mines and will grow to 15,600 m³/h for the new strip mine, Bełchatów.

Transport plays an essential role in the openpit mining of minerals -- being an essential technological link in the extraction process.

A systematic increase of extracted lignite and overburden quantities and the continuously growing depth of the strip mines have produced the change from the rail to a more economic conveyor belt transport. The use of conveyor belts in the Polish mines amounts at present to 80 percent and in 1985, this will come up to 90 percent.

In rail transport, one employs electric locomotives 75 and 100 t and the self-tipping wagons of a capacity 25-65 m³.

The present conveyor belts have the width of the belts 1,200-2,250 mm, speeds 3.15-5.85 m/sek.

The theoretical outputs of these conveyors are up to 2,500-13,000 m³/h.

The lengths of individual conveyors approach 2 km. In the strip mine, Bełchatów, under construction, belts of a width from 1,800 to 2,250 mm with an overburden output to 13,000 m³/h will be used.

In the projected strip mines in the future, we anticipate using belts 3,000 mm wide and with a 20,000 m³/h output.

The power of main transmissions amounts to 40-3780 kw. One employs fabric-rubber belts with a transmission strength coming to 420 kg/cm of the width (average 250).

The employed belts have steel cords and have a strength of up to 3,150 kg/cm of their width.

The transmission stations are mobile (on wheels) and on caterpillar undercarriages, are self-driven, or moved on pontoons, and are also stationary on foundations.

In the strip mine, Bełchatów, caterpillar transmissions will be adapted also to the possibility of waiking transmissions application. The power feeds will be 4 x 1,000 kw. The belts are of a strength to over 5,000 kg/cm.

In its final destination, a transition to the transmission stations of a 4 x 1,500 kw power is planned.

The application of belt conveyor transportation enabled a full mechanization of the technological process.

An automatic remote control of this process with the application of computers is also being introduced currently.

Economic effects of the strip mines depend to a large degree on correct solutions for planned transportation. The share of investments in conveyor

belt transport represents in Polish circumstances about 22 percent of the total investments assigned for the construction of a mine. The exploitation costs of this transport are coming up to as much as 35 percent of the costs of the basic technological system. The application of this modern belt conveyor transportation allowed us in the period of the last 15 years to halve the costs of mass conveyance in our mining.

To carry out numerous auxiliary tasks, accompanying the technological process such as terrain levelling, the execution of roads, shifting of belt conveyors, draining ditches, construction, transport, elevator and overhaul operations, adapted building equipment is employed and is adequately instrumented to meet the requirements of openpit mining.

Advantages of Openpit Exploitation of Lignite

The outlined existing state of affairs and the direction of development of the lignite strip mines confirm the correctness of our decisions especially when we consider the comparative effects of the construction of these mines with the construction of analogous underground mines of hard coal for power uses.

In the production of electric energy, a deciding factor is the fuel cost. The cost of power plant construction and the cost of using either hard coal or lignite is as a rule identical.

As a result of particular technical-economic analyses, one can draw conclusions that can be summarized as follows:

1. Cost of investment, computed per ton of production, of a "standard fuel" of a defined caloric value, for a lignite and for a hard coal mine is almost the same.
2. Investments made to maintain the production capacities in the hard coal mines are 2.4 times higher than is the case with lignite mines.
3. The start-up of production as far as the planned full economic production is concerned is much faster in the case of openpit mines.
4. Two-fold lower are the exploitation costs, three times lower are the staff costs, and four times lower are the costs of materials in the lignite strip mines, and two and one-half times higher is the labor productivity.
5. Far smaller is the number of hazards occurring in the openpit lignite mines, and more than two times lower is the casualty of work.

Based on the Polish experiences in the construction of lignite strip mines and taking into account the modern technological solutions that optimally suit the conditions of our minerals deposition, one can say that development of lignite strip mining was a correct decision.

One has to take into account here, also, the advantageous localization of these deposits enabling the achievement of a large concentration of production, and an opportunity to eliminate long distance rail transportation through a situation of power plants fired with this coal, located in the immediate neighborhood of these mines.

I do hope that this short characterization of our mines and the technical-economic advantages of Polish lignite strip mine exploitation permit an insight into the problems of our mining.

In further reports, the negative results of this mining will be discussed, especially in the sphere of environmental infringement by man and means presented toward counteracting and removing the harmful effects of openpit mining activity.

COAL SURFACE MINING IN THE U.S.

Edgar A. Pash
Supervisory Geologist
Water Planning Division
U.S. Environmental Protection Agency

Coal has always been a major source of U.S. energy needs. However, for a variety of reasons the growth of the coal industry has been relatively stagnant during the past decade in terms of annual production and consumption. In 1973 coal contributed only 18% of the Nation's energy supply, while natural gas and petroleum produced approximately 77%. The remainder was made up by nuclear and hydropower.

The trend of coal usage relative to other energy sources has not been spectacular except perhaps in the negative sense. At the turn of the century coal supplied 88% of U.S. energy needs. By 1950 its relative position had dropped to 38%. Coal was gradually replaced by domestic natural gas and oil due to their competitive costs and greater convenience to the consumer. The use of coal since 1950 has been restrained by various actions such as governmental support of nuclear power development, maintenance of low wellhead prices for natural gas, and the decontrol of residual fuel oil imports on the Eastern coast.

Total coal production has trended slowly upward in recent years, having risen 14% in the 1965-1973 period. Surface-mine production increased 58% during that time while underground-mine production decreased 11%. Coal production in 1974 amounted to 535 million tonnes (590 million tons) about 52% by surface mining methods.

In spite of the small proportion of the U.S. energy market currently satisfied by coal, this resource represents over 90% of our total hydrocarbon energy reserves. It has been estimated that there are over 374 billion tonnes (412 billion tons) of mineable coal reserve. On a Btu basis, 72% of the reserves lie in the Eastern U.S. Of this reserve base some 113 billion tonnes (125 billion tons) are reported strippable. These facts dictate that coal will be called upon to supply a major portion of our energy needs in the future, particularly in face of uncertain supplies of oil and gas.

At the present time the U.S. coal industry is comprised of some 4,700 mines (1973). The mines range in size from one-man operations to large mines employing nearly 1,000 miners. In 1955 the 15 largest coal producing companies accounted for about one-third of total U.S. production; they now account for more than one-half.

Projections of coal demand have been made by the Project Independence activity to 1990. Table I shows estimated annual production, by mining region projected to 1990, for an accelerated development assumption. The data shown

Table 1. Estimated Coal Production Accelerated Development
(Thousand Short Tons)

PRODUCING DISTRICT	1975		1975	1975	1977		1977	1977	1980		1980
	UNDERGROUND	SURFACE	TOTAL	% OF U.S. TOTAL	UNDERGROUND	SURFACE	TOTAL	% OF U.S. TOTAL	UNDERGROUND	SURFACE	TOTAL
I Northern Appalachia											
Pennsylvania	55,770	33,930	89,700	12.0%	62,860	37,490	100,350	10.8%	88,405	57,595	146,000
West Va. (Northern)	42,340	10,160	52,500	7.0%	45,350	11,200	56,550	6.1%	61,200	16,800	78,000
Ohio	17,940	39,860	57,800	7.7%	20,160	44,040	64,200	6.9%	27,755	61,245	89,000
II Southern Appalachia	169,500	92,500	262,000	34.9%	199,800	132,500	332,300	35.9%	300,000	166,630	466,630
West Va. (Southern)	1/	1/			1/	1/			1/	1/	
Virginia											
E. Kentucky											
Tennessee											
III Midwestern											
W. Kentucky	24,410	39,990	64,400	8.2%	24,710	46,090	70,800	7.6%	34,690	64,810	99,500
Illinois	34,930	38,270	73,200	9.8%	37,960	43,540	81,500	8.8%	53,240	58,760	112,000
Indiana	1,740	29,260	31,000	4.1%	1,920	32,380	34,300	3.7%	2,630	44,650	47,280
Iowa	450	650	1,100	0.1%	560	790	1,350	0.1%	830	1,170	2,000
Ark.-Okla.-(part)	110	990	1,100	0.1%	140	1,210	1,350	0.1%	210	1,790	2,000
Kansas-Texas-Mo.-Okla. (part)	--	9,500	9,500	1.3%	--	15,100	15,100	1.6%	--	25,300	25,300
IV Gulf											
Texas (lignite)	--	10,000	10,000	1.3%	--	25,000	25,000	2.7%	--	50,000	50,000
V Northern Great Plains											
Wyoming	1,280	31,720	33,000	4.4%	1,970	47,330	49,300	5.3%	3,640	89,360	93,000
North & South Dakota	--	12,400	12,400	1.7%	--	19,400	19,400	2.1%	--	36,800	36,800
Montana	40	19,960	20,000	2.7%	60	33,440	33,500	3.3%	110	56,890	57,000
VI Rocky Mountain											
Colorado	5,390	3,260	8,650	1.2%	6,180	3,720	9,900	1.1%	9,425	5,575	15,000
New Mexico - Arizona	--	13,500	13,500	1.8%	--	16,000	16,000	1.7%	--	24,300	24,300
Utah	5,210	40	5,250	0.7%	6,160	40	6,200	0.7%	8,690	60	8,750
VII Pacific Coast											
Washington - Alaska	70	7,830	7,900	1.1%	110	12,290	12,400	1.3%	210	23,140	23,350
U.S. Totals	356,180	393,820	750,000		407,940	518,560	926,500		591,125	784,875	1,375,000
%	47%	53%	100%		44%	56%	100%		43%	57%	100%

1/ Figures based on USBM coal district lines; State totals not available.

ed Coal Production Accelerated Development Scenario
(Thousand Short Tons)

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have been modified from "accelerated demand" projections made by the Project Independence Interagency Coal Task Force. These projections assume selected changes in policies or practices that would permit a greater expansion of potential production.

Since our focus here today is on surface mining -- let's examine quickly the projected surface mining picture for the U.S. under the accelerated development scenario. From an anticipated 1975 production level of 357 million tonnes (394 million tons) surface production could progress to 1.45 billion tonnes (1.6 billion tons) in the next 15 years, greater than a fourfold increase. Regionally in 1975, the eastern U.S. will produce some 75% of the total surface production. Projected to 1990, the East is shown to maintain a 60% contribution to the national surface production.

This magnitude of anticipated growth in production capacity is fantastic in an extraction technology that really began after World War II. To appreciate this magnitude it might be useful to briefly trace the history of U.S. surface mining.

Surface extraction of coal in the U.S. had its beginning in 1866 at a site near Danville, Illinois. Overburden was stripped with horse-drawn plows and scrapers and transported by wheelbarrows and carts. In 1877 a steam shovel of wooden construction was put to use stripping overburden from a seam near Pittsburg, Kansas.

Until the 1920's surface mining accounted for only a minute percentage of total coal production. In these early years, however, significant modifications to draglines and shovels were opening the way for profitable surface extraction. Introduction of alloy steels and aluminum in the early 1930's allowed larger capacity machines to be designed.

The percentage of total coal production produced by surface mining operations increased gradually from 1920 until World War II, when surface mining received its greatest boost. Demand for coal increased as a result of the war, and miners turned to surface production because it offered faster recovery with less manpower requirements.

During the years following World War II, improvement in machinery and techniques offered further advantages to surface mining. Improvements in overburden preparation, including introduction of ammonium nitrate fuel oil explosives and rotary drilling, allowed greater productivity from stripping machines.

In 1956, a new era began for the strip mining industry. It was brought about with the introduction of gigantic stripping shovels and draglines. In order to match production capabilities of these larger machines, auxiliary equipment, such as dozers, loaders, scrapers, trucks, and haulers underwent considerable modification and enlargement.

Utilization of larger equipment has been the trend in the past few years. However, a leveling-off in size has temporarily occurred. Operating efficiencies have decreased with introduction of some of the larger machines, and improvements in current designs and efficiencies are the future trends.

The percentage of coal production related to surface mining increased steadily from the mid-1950's until about 1969, when the Federal Coal Mine Health and Safety Act was enacted. After 1969, underground production fell off markedly, and surface mining gained predominance in total production percentage. With new improvements in surface mining techniques, and an abundance of strippable reserves available (especially in Western states), surface mining will continue to account for most coal production in the United States.

In the early years of surface mining, major emphasis was placed on recovery of the mineral, with little or no regard to recovery of the land. Reclamation has now become an integral part of most surface mining operations, and has caused some major revisions in mining techniques. Current practice is to incorporate reclamation with the mining sequence, and not regard it as a separate operation.

Twenty-nine states, at various times, have responded to popular discontent regarding the social and environmental impacts of coal surface mining, by enacting regulatory legislation imposing reclamation controls. Such laws have often been hailed as the strictest in the Nation at the time of passage. Knowledgeable citizens who promoted the new state laws generally assumed that old abuses were ended and that the environmental resources of the community would be fully protected by the state regulatory authority. Seldom has this been the case. Inadequate regulatory authority, staffing and funding; continued rapid expansion of the industry relative to States' capabilities; and political and/or industry influence, have worked against adequate surface mining control.

Disparities among the 29 varieties of state regulations can be shown by a summary of state law provisions:

Summary of Provisions Included in Current State Coal Surface Mining Laws

States having coal surface mining laws-----	29
Hearings:	
Public hearings at time of permit application or at other times-----	14
Enforcement and penalties:	
Closing of surface mines for noncompliance-----	15
Fines for violations-----	23
Bond forfeiture requirements-----	27
Denial of future permit for violation-----	25
Imprisonment for violations-----	7
Bonding:	
Bonding requirements-----	29
Partial bond release-----	8
Performance standards:	
Separation of topsoil-----	2
Slope limitation on reclaimed areas-----	11
Time period for completion of reclamation-----	20
Specified treatment of highwalls-----	5

Source: Congressional Research Service

Deficiencies in reclamation requirements are particularly evident in the provisions relating to Performance Standards.

Now we have pending Federal legislation that will establish, if enacted into law, a national program for the regulation of surface mining of coal and the surface effects of underground mining. The legislation is timely -- if not overdue -- in terms of environmental protection and in view of the certain expansion of the Nation's coal industry. Four years of deliberation in the Executive and Legislative Branches of government have transpired so far, while land was being disturbed by mining at the rate of about 400 hectares (1,000 acres) per week. The law would establish the rules which will govern the extraction of coal by surface methods so that industry can proceed to grow and develop in an orderly and environmentally acceptable fashion.

A very brief overview of the pending law is as follows:

Title I sets forth the findings and purposes of the legislation.

Title II establishes an Office of Surface Mining Reclamation and Enforcement within the Department of Interior and delineates the duties of the Director.

Title III establishes a grant program to fund mining and mineral resources and research institutes in public colleges and universities. These institutes are to train qualified personnel in mine-related fields.

Title IV establishes a fund and a program for the reclamation of abandoned or "orphan" mined lands, and for the relief of areas that will be impacted by the rapid development of mining. All coal mining operators are to be assessed a fee on each ton of coal produced for deposit in the reclamation fund: 35 cents per ton for surface-mined coal, 15 cents per ton for underground mined coal, or 10 percent of the value of the coal, whichever is less, except that the fee will not exceed 5 percent of the value for lignite.

Title V contains the most critical component of the legislation -- the procedures and environmental standards for the regulation of coal surface mining and reclamation. A series of minimum uniform requirements for these activities on Federal and State lands are set forth. These standards deal with four basic issues: preplanning, mining practices, post-mining reclamation, and the protection of water resources.

Title VI contains a section requiring a study to develop, in consultation with the Indian tribes, legislation for surface mining regulation that would recognize the special jurisdictional status of Indian lands. In the interim, mining on Indian lands would still be subject to the environmental standards of the bill.

Title VII provides for the designation of areas of Federal lands unsuitable for non-coal mining.

Title VIII contains administrative and miscellaneous provisions.

It has been estimated that a cumulative total of 10.9 billion tonnes (12 billion tons) of coal will be surface-mined in the U.S. in the 1970-2000 period. Further, it has been estimated that this tonnage will result in approximately 600,000 hectares (1.5 million acres) being stripped, requiring subsequent reclamation at a cost of \$5-\$6 billion. Hopefully, we will have new laws that will return this area (over 2,300 square miles) to a productive condition. As of January 1, 1974 there was an inventory of 389,000 hectares (959,000 acres) of land needing reclamation (Table 2).

If all of us in this room and our associates and peers, and the agencies and companies we represent, in concert with a concerned citizenry, do our jobs properly with an enlightened view, surface mining impacts will be kept within the range of acceptable tradeoffs in the U.S.--in Poland--and elsewhere.

Table 2. Status of Land Disturbed by Coal Surface Mining in the United States and Needing Reclamation as of Jan. 1, 1974, by States (Acres)

State	Reclamation not required by law	Reclamation required by law	State	Reclamation not required by law	Reclamation required by law
Alabama	57,878	118	Montana	300	300
Alaska	2,400	--	Nebraska	--	--
Arizona	150	--	Nevada	--	--
Arkansas	9,451	494	New Hampshire	--	--
California	--	--	New Jersey	--	--
Caribbean Area	--	--	New Mexico	--	25,798
Colorado	4,687	641	New York	--	--
Connecticut	--	--	North Carolina	--	--
Delaware	--	--	North Dakota	10,000	200
Florida	--	--	Ohio	23,926	45,825
Georgia	--	--	Oklahoma	13,858	6,350
Hawaii	--	--	Oregon	--	--
Idaho	--	175	Pennsylvania	159,000	33,000
Illinois	49,748	20,891	Rhode Island	--	--
Indiana	2,500	6,000	South Carolina	--	--
Iowa	25,650	--	South Dakota	790	--
Kansas	43,700	2,500	Tennessee	20,500	5,200
Kentucky	69,000	117,000	Texas	5,470	--
Louisiana	--	--	Utah	120	--
Maine	--	--	Vermont	--	--
Maryland	2,250	3,851	Virginia	18,000	5,014
Massachusetts	--	--	Washington	471	1,010
Michigan	--	--	West Virginia	25,720	51,560
Minnesota	--	--	Wisconsin	234	76
Mississippi	--	--	Wyoming	3,078	2,828
Missouri	75,506	1,250			
			TOTAL	621,887	337,081

Source: U.S. Soil Conservation Service

OPENPIT MINING IN POLAND AND MAIN PROBLEMS OF ENVIRONMENTAL PROTECTION

Roman Kraus

"POLTEGOR"

Chief Engineer, Mining Technology Research

Introduction

Poland is a country very resourceful in mineral raw materials. A significant majority of them is exploited with an openpit method.

Dividing the raw materials exploited by this method into groups, we can mention the following minerals:

The power materials

- Lignite

Chemical raw materials

- Sulphur ore

Compact rocks

- Limestone for the cement industry
- Limestone for the calciferous industry
- Gypsum
- Compact rocks for stone production, building and road building aggregates, and refractory materials as following: granite, syenite, basalt, gabbro, andesite, diabase, quartzite, sandstone, porphyry, melaphyry, marble, limestone, magnesite.

Clay raw materials

- Refractory clays
- Stoneware clays
- Kaolinite clays
- Bentonites
- Ceramics clays
- Clays for the production of light artificial aggregates

Gravels and sands

- Glass sands
- Moulding sands
- Quartz sand for the production of silicate brick and vacuum concretes
- Natural aggregate
- Filling sands

In the last few years a significant increase took place in the excavation of raw materials exploited with the openpit method. In 1950, 72 million tons of minerals were excavated; in 1960, 159 million tons; in 1970, 265 million tons. In 1975, an excavation of about 390 million tons of minerals is expected. As can be seen from the above, the exploitation has doubled every ten years.

Considering the further, rapid growth of building construction, transport, and power engineering, the excavation of minerals by openpit mining will progress at a similar pace.

The biggest share in the total excavation has actually been the following:

- Natural aggregates - 119 million tons
- Cement and limestone raw materials - 87 million tons
- Filling sands - 49 million m³
- Lignite - 40 million tons
- Road building aggregates - 37 million tons
- Raw materials for building ceramics - 27 million tons

The distribution of the sources of raw materials in Poland is not uniform. Omitting the lignite and filling sands deposits, which are discussed in a separate report, five regions have been designated for intensive exploitation connected with mineral deposits (Figure 1).

1. The lower Silesian region contains the largest raw materials resources for the production of crushed aggregates, building stone, kaolinities, and refractory materials;
2. The Świętokrzyski region possesses significantly large amounts of raw materials resources used in the production of binding materials and crushed aggregates;
3. The Karpacki region has rock deposits required for the production of crushed aggregates and regular stone elements;
4. The Śląsko-Krakowsko-Wieluński region distinguishes itself with the occurrence of deposits of raw materials used for the production of cement and crushed aggregates; and
5. The Lubelski region constitutes an important production base of the cement industry.

All the above mentioned regions are situated in the southern part of the country. Outside these regions are found only natural aggregates and clay for building ceramics and also raw materials for the cement industry.

Organizational Issues

Nearly all mining industry in Poland is controlled by the State. Only very small enterprises, such as those which excavate natural aggregates and clays for the production of ceramics and are of significance only to local suppliers, are in private hands. The division, however, of industry into seven ministries, three centers, and also local municipal authorities, and the needs of each of them have resulted in decentralization.

As examples, two regions will be discussed below:

In the Świętokrzyski region, there are as many as ca 4,000 open pits, with an area of 0.02 ha. They occupy a total area of 5,000 ha, so the average area of one pit comes to around 1.2 ha. The State supervises 485 of these pits, or 12.6 percent, but the area occupied by them amounts to 3,376 ha, or 77 percent of the total area of the open pits. Of this number only 65 pits occupy an area greater than 10 ha, and of this number, only 10 have an area greater than 100 ha. The remaining are within the 0.02 to 10 ha area limits. The overwhelming majority of the pits exploit limestones and clays.

In the Dolnośląski (lower Silesian) region there are 871 pits. They occupy an area of 8,258 ha. The average surface of one pit comes to nearly 9.5 ha, so here the sizes of the pits differ from the Świętokrzyski region. The pits supervised by the State, 182 in number, occupy 7,700 ha, or 93.5

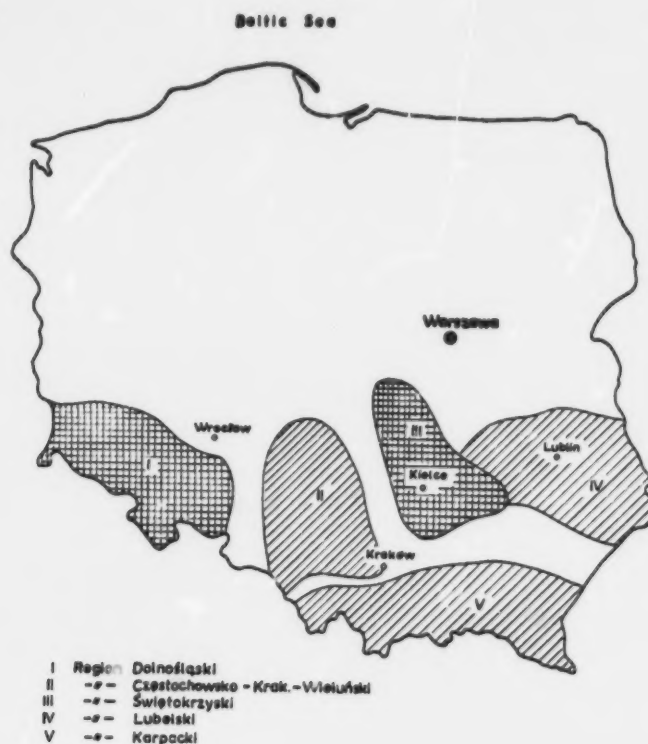


Figure 1. The Map of Regions of Intensive Openpit Mining Industry.

percent of the total area. There are nine pits with a surface of more than 100 ha each, and, of this number, one lignite strip mine occupies more than 3,500 ha, and 109 other pits are from 10 ha to 100 ha. From these are exploited 36 different kinds of minerals. Almost all the mines are strip mines of gravels and sands; granite is exploited in 33 pits, basalt in 24, and the clays for building ceramics in 24 pits. The existing organizational state of affairs does not favor a rational management of the deposits or the protection of the environment and also causes great variation in the technology and processing. Large strip mines as a rule are equipped with machines and installations of an up-to-date technical level, whereas small units often employ simple technologies, are labor intensive, marginally productive, and often very burdensome on the environment.

The necessity for coordination in this area has resulted in Poltegor being entrusted with the role of a center, which determines the directions of openpit mining development and improvement in the whole country. In the framework of this activity, the following is being studied:

- An optimal and a thrifty management of the deposits;
- The most adequate technologies for exploitation and processing;

- The most suitable methods of work study and organization; and
- Problems of environmental protection.

A more efficient and close integration of openpit mining will progress gradually. As this activity progresses, the small open pits will be eliminated and the extraction will concentrate on new, large strip mines. Appropriate decisions by the government have already been made in this respect and are becoming operative.

The integration of the mining industry, apart from its technological and economic effects, will have a fundamental significance for the protection of the natural environment which is considerably easier to control and to enforce in a case of more concentrated mining activity. The State authorities, appreciating the importance of the problem, have issued several decrees concerning environmental protection and especially the protection of the land from mining activity effects. Fundamental here is the "Mining Law" which in appropriate paragraphs defines the duty of the companies conducting the exploitation of minerals in the protection of land.

Examples of Technological Exploitation and Processing

Depending on the conditions of deposition and on the type of mineral, various systems of exploitation are being employed.

In the lignite strip mines, bucket wheel excavators are used and dredger excavators are applied to the overburden and coal. The haulage of the material is made with conveyor belts, the stacking of the overburden with the stackers. Shooting is employed sporadically to loosen harder intercalations of the overburden. A similar technology was adopted in the mining of sulphur ore.

Compact rocks, as a rule, are exploited with the use of explosive materials to loosen them up and crush them. Many types of drilling rigs are employed, both Polish and foreign. The diameter of the shooting holes is from 60 to 150 mm.

Nitroglycerine materials and ammonium nitrates and also the mixtures of the ANFO type are used. For the loading of material, depending on the amount of excavation, one uses mechanical shovels having a shovel capacity from 0.75 to 2.5 m³. For haulage, self-tipping trucks of various types with a capacity of 3.5 to 22 tons are used. The exploitation is carried out on one or two stages, the height of the stage being 15 m. Blocks to the production of regular elements are being excavated with the aid of cableway cranes, or cranes of a Derrick type.

In the mines of refractory clays, bucket wheel excavators with an output to 300 m³/h and a bucket capacity 50 or 100 are used with a belt conveyor transport to the outcrop and to the overburden stacking.

The clays for building ceramics are exploited with the longwall or the shortwall method on one, two, or three levels. The height of the slopes is from three to eight m, the depth of exploitation is about four to twelve m. Shovel excavators of various types with a shovel capacity of about 1.0 m³ are used for working, or the dredger excavators on a caterpillar or rail running gear. The material as a rule is transported on self-tipping cars, conveyor belts, or trucks.

Gravels and sands are exploited from small open pits with shovel excavators of various types and transported on trucks; the large strip mines are equipped with bucket wheel excavators and belt conveyors or train services; the underwater deposits are exploited with floating scoops.

The mechanical processing of raw rock materials employs various technologies, depending on the purpose. Lignite in a small quantity (4.5 percent) is sorted for heating purposes or crushed multigrade for briquetting. Sulphur ore is crushed, classified, floated, and melted. The raw materials in the production of refractory materials go through working processes depending on the type, thus: refractory slates are being comminuted, classified, roasted and electromagnetically enriched; quartzites and magnesites are comminuted, washed and classified; and, dolomites are comminuted, roasted and classified. The raw materials for the production of multigrade aggregates are crushed and sorted (breakstone or key aggregate) and additionally granulated (grits). Natural aggregates are also washed, when polluted with clays. The raw materials for building ceramics are comminuted and blended for the whiteware--crushed, classified wet, dried, and ground.

This short description of mining and processing technologies was necessary to discuss their environmental effects.

Harmful Influence on the Environment

The chief negative factor of openpit mining activity is the transformation of the land surface. Regardless of whether the exploitation is carried out with a slope system or a cavity system, it carries with it a multitude of changes transforming the original surface of the terrain. Such changes occur mainly in the region of the activity, but also often go some considerable distance from it. The concentration of changes transforming the land surface leads to a degradation of the mine landscape and the degradation of its environment.

The morphology of the transformed land surface depends on the following factors:

- Natural morphology of the terrain,
- Lithology of the rock complexes forming the given region of the deposit, and
- Exploitation system and stacking of the wastes from the exploitation.

As a result of the emerging mining activity, there are two types of direct land surface transformations: the open pits and the stacks of wastes. They cause, first of all, the changes in the original, natural terrain morphology. Moreover, the following phenomena often are important:

- Influence of rock masses accumulated on the stacks of wastes, through additional stresses in the soils, and an infiltration down to the subsoil of the waste weathering product;
- Unbalance of the hydrogeological conditions--changes in the ground water table level;
- Changes in the microclimate in the region of the open pits and stacks;
- Development of the erosion processes on the surfaces of the (walls) slopes of pits and stacks, and the consequences of weathering, which penetrate frequently to great distances;
- Seismic shocks effected by blasting operations; and
- Soils degradation on the terrains of the strip mines and the adjacent regions, connected with the above phenomena.

All these phenomena, occurring mostly in connection with a direct land transformation, influence negatively the environment from the moment when the

access to the deposit is being gained. The characteristic property of the majority of changes degrading the landscape is their long lasting period of influence which is longer than the exploitation period. Direct transformation of strip mine terrain and stacks are long lasting. After the exploitation, these transformed terrains acquire a character of wastelands. The morphology of these terrains is always vastly different compared to the original surface configuration.

Very often the strip mines are accompanied by processing plants or industrial plants, working the exploited mineral. They are also the source of various kinds of influences degrading the environment as, for instance, the pollution of waters with sewers, the emission of dusts into the atmosphere, and the development of dumps with dry or wet wastes.

Work Undertaken to Improve the Environment

In the two regions mentioned above, through investigations of the present state of affairs, the rehabilitation of the terrain was carried out and designs for the near future were made.

It was established that the process of reclamation should come into existence simultaneously with mine designing and planning. This would allow one to avoid errors and limit the area of damage.

The choice of the technology to be used is also significant to the size of the exploited terrain. An increase in the depth of exploitation, particularly necessary in the group of ceramic raw materials and natural aggregates, will limit considerably the occupied area.

Examples have been mentioned as to how great the growth of the mining business is. This growth provides possibilities for improving the situation. In place of the hundreds and thousands of small strip mines, one can obtain an equivalent output from large units and, in this way, limit to a great extent the surface occupation and pollution. Similarly, the reclaiming work in a concentrated effort can be better organized and therefore will be faster and more effective.

For further improvement in this area, an elaboration of the guiding principles of postindustrial terrains reclamation began, which included the totality of mining activity. Such principles will have the character of an obligatory, legal act. The goals can be defined as follows:

- Total embracement of the problems of the protection of agricultural and forest lands and the reclamation of terrains transformed by industrial activity;
- Determination of formal rules of procedure in the design, construction, and exploitation of the mines and waste stacking from the point of view of the technological relation with the protection of the land and its useful rehabilitation;
- Economic adaptation of the reclaimed terrain, with responsibility in the mining enterprises; and
- Establishment of necessary amendments in the regulations concerning the protection and reclamation of terrain.

Parallel with the work conducted on the reclamation and protection of land, investigators are working on the openpit influence on the transformation of water conditions which also have an enormous significance for soil depreciation. At some further stage of work, the development of guiding principles is planned for the control of damage in water management.

In addition to the above research, other fields of natural environmental protection are being conducted, namely:

- Protection of employees from excessive noise effects,
- Protection against excessive dusting,
- Limitation of vibration influence,
- The limitation of the seismic shock effects caused by the blasting, and
- Limitation of wastes quantities in processing technologies.

In some fields, positive results have been achieved already, namely, cabins have been constructed which are soundproof and dustproof and very effective in reducing noise levels. These are assigned for service workers at points of a great noise intensity (i.e. near conveyor belts). The improvement in blasting techniques permits considerably better effects of shooting, with a simultaneous decrease in the seismic waves influence caused by blasting work.

Finally, one has to mention the new lately introduced restrictions. The local authorities in Poland have defined zones of protection for agricultural and forest activity, zones of protected landscape and recreation. This necessary action, however, creates considerable difficulties for mining, because no exploitation can be situated on these terrains, no matter how valuable the deposit that is localized there, and no matter how small the potential damage may be.

In connection with this, the mining industry intends to develop reliable criteria on the harmful influence of mines on an environment, which will allow one to classify strip mines in an appropriate category of harm class in an early stage of planning.

This will contribute to the search for appropriate technological solutions, where the planned mine should suit the conditions and allow its construction in the protected zone terrain.

These and other investigations will continue, and new ones will be forthcoming. The enormous development of openpit mining requires intensive work, aiming at a constant reduction in the harmful effects on the environment.

COAL REFUSE DISPOSAL PRACTICES IN THE
AMERICAN COAL INDUSTRY

G. L. Barthauer
Vice President
Consolidation Coal Company

Your Chairman has asked me to review with you practices in the American coal industry with respect to the disposal of coal refuse originating from coal mining and coal preparation operations.

I'm certain you realize that this is a very complex subject and we have no time to go into specific engineering details relative to the design of solid waste disposal sites. Rather, this time can best be spent by presenting to you a general overview of past and present practices for coal refuse disposal. Although the emphasis will be on environmental considerations, a number of my comments will be addressed to the safety problems associated with refuse disposal.

As you know, coal refuse disposal involves two quite separate and distinct problems. The first involves disposal of fine refuse, i.e., those particles having a size consist of -28 mesh (-0.5 mm). These materials normally are removed from the preparation plant water circuit as a thickener underflow and pumped away from the plant area in slurry form.

The second refuse disposal problem is that of getting rid of the coarse material rejected from the coal washing operation. I want to discuss each of these problems separately, starting with fine refuse disposal.

In the early days of the coal industry in this country (as I suspect was also the case in Poland), the problem of fine coal refuse disposal simply didn't exist. Coal cleaning was almost entirely a manual operation consisting of selective underground mining followed by hand-picking of the raw coal to discard coarse rock. Rather, the fine fraction ended up with the clean coal.

The demand for higher quality steam and metallurgical coals eventually led to the widespread adoption of wet cleaning processes. And here, of course, the removal, processing, and disposal of fine coal refuse became an ever-increasing problem. The severity of the problem varied from area to area for reasons which we will look into later. But it was a problem -- and the later arrival of the continuous miner with its higher production of fine coal only aggravated the situation.

However, disposal of the fine refuse wasn't too difficult in the early days of wet coal washing plants. Usually such plants were located near streams and, quite frankly, those streams had a rather distinct grayish color while the preparation plants were operating. As we look back on those days from an environmentally conscious 1975, let's don't be too critical of the coal operator. His competition was fierce, he needed to cut every corner to

survive, and his customer wasn't the least bit inclined to pay a higher price for coal which might be produced in a more environmentally sound manner. I might also add parenthetically that the "upstream-downstream" disposal method was common practice until recent years -- and still remains a major problem with municipal sewage wastes.

At any rate, times and attitudes changed and eventually this practice was discontinued. At that time, operators turned universally to impoundment and permanent storage of fine coal refuse. Streams in the coal-producing areas no longer run gray or black. Local wits frequently point out that we can now see clearly the beer bottles, tin cans, and rubber tires in the stream beds.

As I mentioned previously, the problems of fine coal refuse disposal vary widely from one part of the country to another. The reasons for this are two-fold; first, the varying amount of fine coal refuse generated per ton of clean coal produced and, second, the topography of the area in which the coal is mined.

Let's look first at the amount of fine refuse produced per ton of clean coal.

As you may know, our major bituminous coal-producing regions are the Appalachian coal region in the eastern part of the United States and the Midwestern coal region extending several hundred miles on either side of the Mississippi River. The Appalachian region can be further subdivided into the Northern and Southern Appalachian coal fields. Each of these areas contains coals having distinctly different chemical and physical characteristics. The combination of these chemical and physical characteristics determines, to a large extent, the magnitude of the fine coal refuse disposal problem.

For example, in the Southern Appalachian region where most of the low and medium volatile coal production is located, the coals are extremely friable. Run-of-mine raw coal frequently is as high as ninety weight percent -3/8". The -28 mesh fraction frequently comprises as much as twenty-five percent of the entire product.

In the Northern Appalachian area and in the Midwestern coal region, matters are considerably different. Only about ten percent of the run-of-mine coal lies in the -28 mesh fraction. So here we see one difference which makes the disposal problem much more severe in Southern Appalachia than in other coal-producing regions. Over twice as much fine coal refuse per ton of clean coal product was generated in this area as in other coal regions. And adding to the difficulty is the terrain of Southern Appalachia limiting the selection of suitable disposal sites.

However, once fine coal cleaning became a reality -- particularly froth flotation -- matters came back into balance. The Southern Appalachian coals are, as a rule, high-grade metallurgical coals, used for iron and steel manufacture both in this country and abroad. Most of the coals are low in sulfur and contain little or no pyrite. Thus, in view of their higher value, most preparation plants in these areas now have froth flotation units which recover anywhere from fifty to seventy-five percent of the material in the fine coal fraction. This substantially reduced the volume of fine coal refuse.

Let's turn now to slurry impoundment methods which were adopted when the industry turned to this method for fine coal refuse disposal. Here, the topography of the area was the determining factor.

In the mountainous regions of Appalachia, the problem wasn't too difficult. The operator simply located a nearby valley of suitable size, built an embankment across the valley of the breaker rock or coarse coal refuse, and

pumped the slurry behind the embankment. The embankment acted as a coarse filter and clear water flowed from the downstream side of the embankment. As the slurry volume increased, the height of the embankment was raised as needed. After the valley was filled, the operator simply abandoned the area and moved to another valley.

In the flatter Midwestern coal regions, the problem was almost as simple. Dikes were constructed of coal refuse and slurry pumped into these dikes. Again, the coarse refuse acted as a filter, and water, free of solids, emerged downstream of the impoundment walls. This scheme had several advantages; it not only took care of the fine coal refuse problem but it also provided a place to put part of the coarse refuse. Again, once an area was filled, another was constructed.

A third method in common use was to build diked areas on top of the coarse refuse pile or to scoop out pockets to accept the slurry. Water filtered through the pile and the dried slurry was later covered with coarse refuse.

Now these methods left something to be desired from an environmental standpoint, both with respect to air and water pollution.

Air pollution problems were common. These were the result of fugitive dust blowing from the surface of dried ponds during periods of high wind velocity. Short-term solutions can be achieved by spraying organic polymers on the surface to form a "windproof" crust; permanent solutions involve actually re-vegetating the surface of the pond.

Water pollution problems were serious, particularly where the coal contained significant amounts of pyrite as is the case in the Northern Appalachian region and in the Midwestern coal fields. The combination of water, air, and pyrite resulted in the formation of vast quantities of acid drainage, polluting nearby streams, destroying aquatic life, and, in some cases, affecting drinking water supply. With the passage of water pollution control legislation, it became necessary to construct the dikes of clay and clean earth, and in many cases, rock, rather than coal refuse. No longer could wet fine coal refuse be stored on or behind coarse acid-forming material.

Now the acid drainage problem was virtually nonexistent in Southern Appalachia. As I pointed out previously, these high-quality metallurgical coals are virtually free of pyrite. So the operators in that area continued their long-standing practice of confining fine coal refuse in valleys behind embankments made of coarse mine rock or coarse refuse.

And then, on February 26, 1972, came the Buffalo Creek disaster. On that date, a refuse embankment in West Virginia, used to impound slurry high above a narrow inhabited valley, failed. Although there were not witnesses to the actual failure, it appears clear that excessive rainfall in the watershed above the impoundment raised the water level to a point where it overtopped and breached the embankment. A torrent of water and slurry was released into the narrow valley below and, during a short time span in the early morning hours, one hundred twenty-five people lost their lives and millions of dollars worth of property was destroyed.

The Buffalo Creek incident initiated an immediate and extensive investigation and surveillance program throughout the mountainous areas in which similar impoundments were located. All types of federal and state agencies were involved, each attempting to define the degree of hazard associated with particular impoundments. Corrective orders were issued on scores of impoundments and many operators were ordered to cease pumping until corrective measures could be taken. It was a period of great confusion on the part of agencies and operators alike.

The initial thrust toward correcting existing impoundments was directed toward constructing large emergency spillways adequate to handle excessive rainfall and runoff without risk of overtopping the embankment. And they were large spillways!! For example, the general guideline was to insist on a spillway and outlet channel of sufficient size to handle a volume of runoff associated with a "maximum probable precipitation" event. Now, throughout the Appalachian region, normal annual rainfall is between 40 and 45 inches per year. But a "maximum probable precipitation" event for the same area is defined as 26 inches of rainfall over a period of six hours. You can imagine the problems involved in building such spillways in existing structures located downstream of an extensive watershed.

Frankly, the first year after Buffalo Creek was a period of recriminations, confusion, and uncertainty. Neither the industry nor the agencies had the necessary talent or expertise to adequately evaluate the structural stability of existing embankments. Civil engineering consultants were used extensively by all parties and slowly a rational and more sophisticated approach to such evaluations evolved.

I won't attempt to discuss in any detail the approaches used for stability evaluations. These are set forth quite adequately in a recently issued publication prepared for the Department of Interior's Mine Enforcement and Safety Administration. This publication entitled "Engineering and Design Manual for Coal Refuse Disposal Facilities" is an extremely comprehensive work. I have a copy with me and I highly recommend that you obtain a copy for your own use. I'll mention only that such evaluations are based upon borehole data to determine water level, phreatic surface, internal pore pressure, and the types of materials comprising the embankment. From these data, a variety of calculations can be made to determine stability and factors of safety.

At any rate, impoundments are now being constructed in a manner vastly different from that used in the past. Rather than allowing filtration through a coarse embankment, the slurry is now completely confined by an impervious structure, carefully keyed into the valley walls. Water is removed from the impoundment by periodic pumping after the fine solids have settled.

All of these factors have provided an incentive for the American coal industry to find other methods of disposing of fine coal refuse other than traditional impoundment. So far, our success has been somewhat less than spectacular.

One method used has been to pump the slurry into boreholes sunk into old abandoned deep mines. This method has its limitations. Obviously, all preparation plants do not have an abandoned mine nearby. Second, even if one is available, adequate mine maps showing the exact location of voids, entries, and pillars may be difficult to locate. And, of course, roof falls may well create barriers to flow.

Another method which is being explored is that of closing the fine coal circuit by centrifuging or filtering the slurry, returning the centrifugate to the plant, and disposing of the centrifuge cake with the coarse refuse. For example, at one of our plants in Alberta, Canada, we use a screen bowl centrifuge to remove a significant portion of the fine solids. However, the centrifugate still contains significant amounts of fine refuse which still must be settled out in an impoundment. However, the total amount of impounded material is reduced significantly.

The high moisture content of the centrifuge or filter cake can also present problems if it is mixed with coarse refuse. If present in sufficient

amounts, the coarse refuse is softened to a point where it will no longer support haulage trucks or compacting equipment. So we really haven't found a good alternative to impoundment -- but we're still trying.

One final word with respect to slurry impoundments. We are getting rid of a few of them. The energy shortage and the increased value of coal have made it profitable in certain instances to recover fine coal from some of the old slurry ponds. The slurry is mixed with clean coarse coal and ultimately finds its way into steam markets.

And now let's turn to the problem of coarse refuse disposal.

Again, looking back to the early days of the American coal industry, most coal was selectively mined underground with considerable care taken to exclude as much rock and slate as possible. That delivered to the surface was hand-picked and the reject material went to the refuse pile. The amount of material going to the refuse pile was relatively small, but oddly enough, in many cases contained substantial amounts of coal. In an effort to maintain quality, many rock-coal-type particles ended up as rejects. Many of these refuse piles are being reprocessed today. Crushing of the refuse separates the coal from the rock and, using today's modern cleaning practices, large amounts of high-quality fuel can be recovered.

The advent of wet coal cleaning processes increased the refuse disposal problem. Much of the rock and slate which previously had been left underground was now brought to the surface and easily separated from coal by specific gravity methods. Later, continuous mining methods, using full-seam mining, further aggravated the problem. At the present time, approximately twenty-five percent of the raw feed entering a preparation plant ends up as refuse.

Until recently, disposal practices for coarse refuse had changed little, although the type of disposal again varied according to the topography of the area.

In mountainous regions, several types of disposal are used. These are as follows:

1. Cross-Valley Fill - Refuse is initially deposited across the narrow neck of a valley. Succeeding refuse deposition takes place further up the valley until the refuse pile is at an elevation corresponding to the valley ridges.
2. Valley Fill Dump - Refuse is dumped initially into the upper end of a valley until a sufficient amount accumulates to support truck travel. Additional refuse is then end-dumped over the edge until the valley is filled.
3. Side-Hill Dump - Refuse is simply dumped down a hillside from the top of a ridge, resting eventually at its normal angle of repose.

In flat land -- such as our Midwestern coal regions -- the refuse is simply deposited in waste heaps, usually ending up in the general shape of a truncated cone.

Refuse is delivered to the disposal area by a variety of means. In flat land and gently sloping terrain, trucks carry the material from the refuse bin directly to the disposal site. Where slopes are of the order of 15° to 20° , conveyer belts usually carry the refuse to a refuse bin located high above the preparation plant. From this point, trucks complete the journey to the disposal site. If slopes are greater than 20° , an aerial tram is used for transport.

I'm certain you know that refuse piles, unless carefully planned and operated, can create substantial safety and environmental problems. I won't

dwell at any length on the design features relative to safety except to say that the most critical factors relate to the steepness of the slope faces and the installation of a water drainage system adequate to prevent water impoundment or saturation of the dump to a point where the slopes cannot be maintained. All of these design features for different types of dumps are adequately described in the publication which I mentioned previously.

Environmental problems associated with coarse coal refuse disposal also fall into the general areas of air pollution and water pollution.

The most serious air pollution problem is that related to fires resulting from spontaneous combustion. Early dumping practices seldom involved compaction of the refuse to reduce air circulation throughout the dump. As a result, many dumps caught fire, releasing large quantities of smoke and sulfur oxides. Such fires, once started, are extremely difficult to control. Present practice involves spreading the refuse in relatively thin layers and compacting with a bulldozer or heavy scraper. Fires on new refuse dumps are virtually unknown; however, many abandoned dumps are still actively burning -- although one by one, they are being extinguished.

Water pollution problems are serious, both in the Northern Appalachian and Midwestern coal fields where significant amounts of pyrite are associated with the coal. Again, pyrite is oxidized to soluble iron and sulfuric acid. Rainfall carries these soluble materials into nearby streams, adversely affecting any aquatic life which may be present.

Present practices on new refuse dumps call for covering the side slopes with earth and establishing vegetation as the dump increases in height. This serves a two-fold purpose. First, it excludes air from the refuse, minimizing the oxidation of pyrite. Secondly, it controls erosion on the slopes, thus preventing deposition of fine solids in the stream beds. A rather elaborate system of toe drains and drainage blankets is also being used on new dumps to carry away water which may fall on the dump and decrease its mechanical stability. Prior to abandonment, the operator is required to put a thick cover of clean earth on top of the dump and establish vegetation.

I might point out that it's much easier to control these problems on a new refuse dump than it is to correct similar problems on an old dump. And literally thousands of "old" refuse dumps exist in the United States, many of which have been abandoned decades ago.

Now, the magnitude of the potential pollution problems associated with refuse dumps has led a number of environmentalists to believe that they can never be controlled. Consequently, there is a substantial movement to force the operator to take the refuse back underground, either by flushing through boreholes from the surface or by mechanical stowing in worked-out areas.

There seems to be a widespread belief in this country that the Europeans have solved all their refuse disposal problems in this manner. Having visited a number of the coal fields in Europe, I find this hard to believe. At any rate, our National Academy of Science has recently completed a study of the possibility of underground waste disposal. The Academy study concluded that underground disposal was technically feasible in "abandoned" mines, mines having long wall operations, and mines using partial recovery room-and-pillar methods. Economic and safety factors leave something to be desired, however, particularly in active operations. Certainly, a great deal of further research, development, and demonstration must be carried out before underground waste disposal becomes accepted practice.

Before concluding my presentation, I would like to show you several slides illustrating some of the matters I touched on during the discussion.

This concludes my comments on waste disposal practices in the American coal industry. I'll be happy to answer any questions which you may have.

HYDROGEOLOGICAL ASPECTS OF ENVIRONMENTAL
PROTECTION IN POLISH OPENPIT MINING

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Introduction

Among the many directions in which openpit mining exerts its influence on the environment, the greatest impact in Poland has undoubtedly been its effect on the ground water. Occurrences of this kind have particular significance not only in Poland, but also in all of central Europe, where the mining activity is conducted in the majority of cases below the ground water table. The growing shortage of raw materials, rising prices, and the need to search for substitute raw materials, force us to reach deeper and deeper with the open pit, where the water saturation of layers is stronger. Examples of this are also the planned large-scale activities in the U.S. to exploit oil shale in the Rocky Mountains or the sands bearing crude oil in the Alberta Province in Canada. One has to consider that such problems will grow in the whole world as, on one hand, the demand for raw materials rises, and, on the other hand, as the resources existing in favorable conditions -- that means above the ground water table -- become exhausted.

So then, from a hydrogeological point of view, the strip mines can be divided into the following groups:

- I. Pits in which the activity is conducted above the ground water table:
 - a) Situated above the level of the surrounding terrain -- contour mining -- encountered only in the mountains,
 - b) Below the surrounding terrain, but still above the static ground water table.
- II. Pits in which activity is conducted below the static ground water table which, in order to enable the excavations, was artificially drawn down:
 - a) Through the open pit itself, which constitutes a draining element, and within which the water accumulating at the lowest point is pumped away,
 - b) By means of specially made draining arrangements, which prevent uncontrolled water from coming into the pit (well systems, underground galleries, special draining holes, etc.).

In Poland, the drawing down of a ground water table in pits which are included in group II fluctuates from a few to several hundred meters. In order

to secure such a lowering of the water table, regardless of the kind of draining system employed, quantities of water ranging from a few to 120 m³/min. are now being pumped away in pits under operation, and there is a pit under construction which will require about 300 m³/min. of water to be pumped away.

A deep depression and significant amounts of pumped water cause around the dewatered areas depression cones of radiuses exceeding in some cases many kilometers. Within these cones the water table is lowered to a magnitude varying from S maximum in the center of the cone, to S → 0 on its boundary. The generally stated phenomenon given above leads to disturbances in water conditions of the given regions, and such disturbances find their expression in the vanishing of water in wells and other commercial water intakes, and sometimes in a deterioration in vegetation conditions. This issue forms the first group of hydrogeological problems of the environmental impact in strip mining and could be generalized as a group of quantitative problems.

After the exploitation of a mineral is ended either because of the exhaustion of resources or because of the loss in profits, the open pit remains left behind. It can be:

- I. A dry pit when it is situated above the static ground water table;
- II. Maintained in a dry state with the existing drainage system still working from the exploitation period;
- III. Flooded with water when its position is below the ground water table and the drainage system working during the exploitation was taken out.

Such open pits are often left in industrialized areas and are of great interest to various companies as potential dumps for their industrial wastes.

In Poland, the Industry of Coal and Power Engineering which has significant amounts of coal refuse and ashes in excess of their economic utilization possibilities shows interest in utilizing open pits as disposal sites. This apparently rational utilization conceals in itself, however, a potential threat in the form of ground water pollution with leached substances coming from the dumped wastes. Such substances in a ground water environment can later migrate to places where water is being put to usable purposes. This activity constitutes the second group of hydrogeological problems of the environmental impact in openpit mining, which can be termed as the group of qualitative problems.

Influence of Ground Water Table Drawdown by Strip Mining on the Adjacent Regions

Polish regulations require that, even during the geological investigation and design of a mine, proper research and investigation be made so that the effect of the mine on the water condition in adjacent regions can be determined.

The construction project and exploitation plan of the mine, containing the estimated elements and proposals for limiting the negative effects on the environment and the measures for preventing damage, have to be sanctioned by the local administrative authorities who can impose their conditions.

Necessary to such an analysis of these phenomena is, first, the determination of the boundary and the initial conditions of a given region -- considered as the initial data required to forecast any changes.

The boundary conditions are understood to be the limits of the aquifer in its horizon and its thickness, the presence of the limiting flow contours

(impervious complexes), the contours of constant supply (rivers, lakes), the ground water head and the hydraulic connections with other aquifers. Also to be determined are the permeability parameters, i.e., the transmissivity and the storage coefficient of the aquifer. Considering that the majority of hydrogeological occurrences associated with deep dewatering of mines has an unsteady character -- the variable in time magnitude of depression and also the variable size of dewatered area -- the totality of the phenomena is examined, in the majority of cases, in an aspect of unsteady flow conditions based on general principles of Theiss and Hantush methods.

Having at one's disposition these data and the design of a drainage system, the forecast of depression cone development can be made, depending on needs, from calculated methods or with methods of a digital or physical modeling in combination with the structural analysis. The area around the depression center could be divided into radial zones in such a way that the boundaries among the zones are parallel to the direction of the streaks of ground water streams, with a simplifying assumption, that no large-scale exchange of water occurs between the sectors (Figure 1). The number of sectors depends on the degree of variation of hydrogeological conditions and on the required accuracy of analysis. However, one has to strive for the boundary conditions and the hydrogeological parameters in the particular sectors to be as uniform as possible. Following

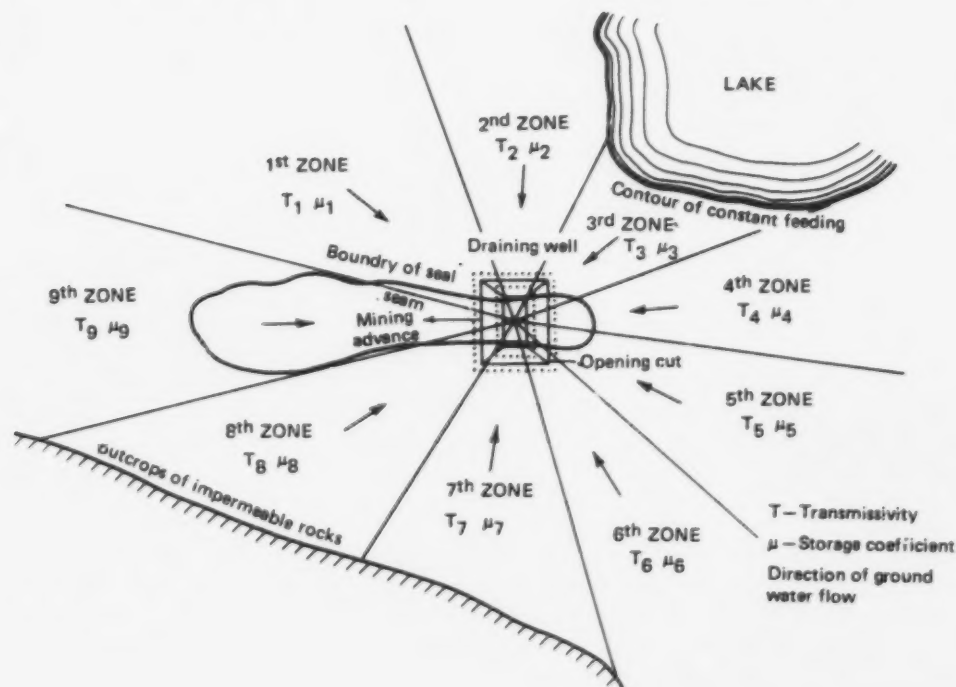


Figure 1. Scheme of Radial Zoning of the Aquifer for the Estimation of Depression Cone Development.

this, the progress of the depression cone for particular zones could be determined with the use of simple calculating methods or with digital methods. Depending on the filtration conditions, methods are used for calculations based on the principles of a steady or unsteady filtration.

For more variable and diverse geological structures, physical modeling is easier to identify the problem system than is the case with digital models. It is based on a simpler exchange of particular elements, copying the parameters of a given stratum, and the conditions of its feeding without any necessity for a reconstruction of the entire program, as would be the case when applying digital modeling. For the physical modeling, an electrical network analogue of the resistant type or the resistant-capacitive ones, and the slit type analyzers of the Hele-Shaw type are employed. The use of the above methods connected with interpolation and structural analysis enables the determination of the extent of the depression cone $R = f(t)$ and also the position of the ground water table in any optional point of the given area and at any discretionary moment of time, $H = f(x, y, t)$. (Figures 2 and 3).

The above data are further utilized for the determination of:

- Diminished output in existing commercial water wells, taking ground water;
- Scope of work, which should be carried out in order to provide the required output of wells through the deepening of existing wells, through making new ones, or delivering water from other sources;
- Losses in agricultural and forest land uses, expressed in diminished crops, or as a necessary change in the manner of land use.

The first two tasks are being solved with the aid of generally known procedures in hydrogeological methods of water intake construction.

The third problem is the matter of the relationship of hydrogeology and agriculture or forestry. For the evaluation of hydrological conditions and effects on water management in superficial soils, three prevailing types of water conditions in the soil, depending on the position of the water table, have been distinguished in pedology by Professor Skawina:

Type I: Precipitational-retentional, in which the vegetation uses exclusively the atmospheric precipitation stored in the pores of the soil;

Type II: Intermediate, in which, depending on the seasonal ground water table fluctuations, the vegetation uses either the ground water (in a spring) or the precipitated water (in summer and autumn);

Type III: Ground water, in which the vegetation uses the resources of the ground water, the water table of which or the capillary zone are within reach of the root systems.

In the first type of condition, the lowering of the ground water table has no effect whatever on the vegetation. In the third type such influence is very pronounced, and in the second type it is felt only partially or seasonally. For types II and III, a method of quantitative evaluation of diminished production capacity of the soil, based on an elementary formula, was developed.

$$U = \frac{A_1}{A_2} \cdot 100 \%$$

where:

- U - percentage of the lowered production capacity of the soil
- A_1 - a numerical indicator of changes in the water management
- A_2 - a numerical indicator of changes in the retention capacity of the soil.

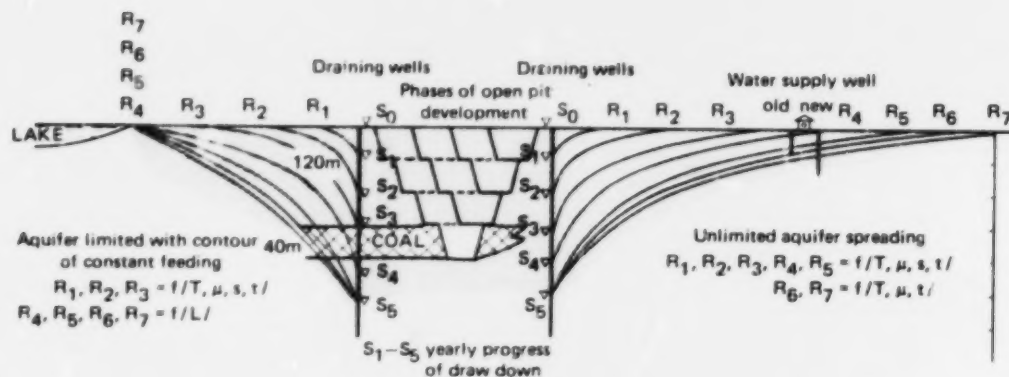


Figure 2. Schematic Section of the Cone of Depression Development/Outside Pit/With the Reference to Deep Drainage Progress and Phases of Openpit Extension.

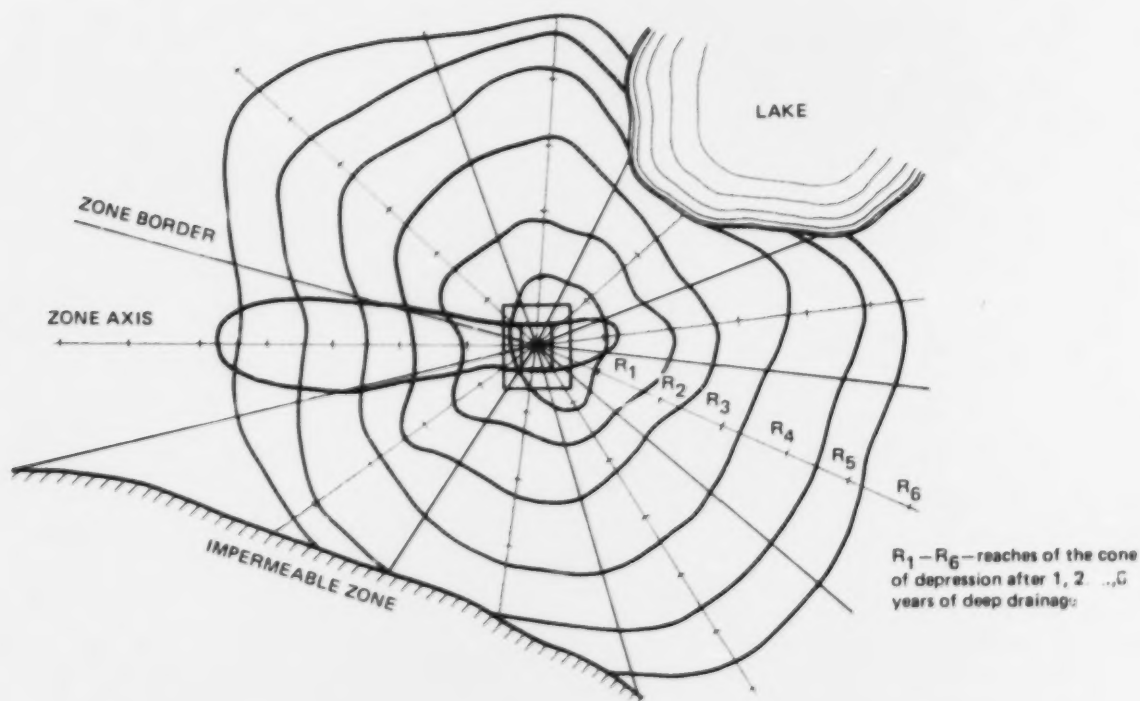


Figure 3. Schematic Map Illustrating the Spreading of the Cone of Depression on the Earth Surface.

Dependent on the initial soil humidity and changes in the type of water management in the soil, the coefficient A_1 value is 0.2 to 1.0. Whereas the coefficient value $A_2 = A_{21} \cdot A_{22}$.

where:

- A_{21} - Indicator of a retention capacity of the mineral phase of the soil profile
- A_{22} - Indicator of the improved retention capacity of the mineral phase, dependent on the thickness of the humic stratum.

For a uniform, in a granulometric respect, soil profile, the value of the coefficient A_{21} fluctuates within the limits from 1.0 for the loose coarse sand to 3.3 for the robust clay sand and to 10.0 for the loam formations. For a diversified soil profile the value of a coefficient A_{21} is defined from separate formulas. The value of the coefficient A_{22} however fluctuates from 1.1 (for a 15 cm. thickness of the humus stratum) to 2.0 (for a 35 cm. thickness, respectively). Depending on the depth of a water table lowering, two degrees of desiccation off are distinguishable:

1. A small-scale drawdown, in which the type of water management changes by one step, namely, the type II changes into I, or III into II;
2. A large-scale drawdown in which the type of water management changes by two steps, which means the type III passes into type I.

Two groups of changes in soil usefulness could be distinguished. The qualitative changes in agricultural usefulness and the habitat tendencies of a forest in initial ground water management (type III), occurring under the influence of draining are illustrated by the following examples:

- Robust cereal-pastoral complex under the influence of a first step draining off passes into a weak cereal-pastoral complex, and under the influence of the second step into a weak or very weak rye complex;
- The very good and good fodder producing areas change under the influence of draining of the first step into a weak cereal-pastoral complex, and under the effect of a second step of draining off into a faulty wheat complex, or into a weak rye complex;
- A wet high forest of average fertility changes under the influence of the first step draining off into a forest with a deep ground water table, where the culture is old, and into the waste land, when the culture is still young; whereas, under the influence of a second step draining away, it changes into a forest with poorest soil, or a waste land, respectively;
- A swampy high forest under the influence of first step draining off remains a swampy forest with a lowered valuation, and under the second step draining-off effect it changes into a waste land.

The analogical changes for soils with precipitation ground water management (type II) are illustrated by the following examples:

- A robust cereal-pastoral complex changes into a wheat complex, good or faulty,
- A weak cereal-pastoral complex changes into a weak rye complex,
- A high forest of average fertility with a deep water table changes into a poor soil habitat forest,
- A wet high forest of average fertility changes into the poorest soil habitat forest (whereby, in cases of both high forest types, the young cultures change into waste lands).

The quantitative changes, however, in agricultural and forest lands productivity, is best illustrated by the following example:

Research carried out for a large lignite strip mine, within its depression cone, with sand formations of 70-80 percent, has obtained a diminished productivity for:

- Soils of a good wheat complex by about 10 percent,
- Soils of a very good rye complex by about 20 percent,
- Soils of a good rye complex by 25 percent,
- Soils of a weak rye complex by about 35 percent,
- Soils of a very weak complex by about 20 percent,
- Soils of a robust cereal-pastoral complex do not indicate a diminished productivity but they change their agricultural usability (versatility),
- Soils of a cereal-pastoral complex by about 50 percent,
- Meadows-pastures by about 60 percent, or are changed into arable lands.

Where the forests are concerned, then:

- Forests of the xerophyll or mesophyll habitat may well not change their character and productivity in an essential way,
- Forests of the hydrophyll environment -- swampy high forests and alder groves -- change into waste lands; the wet, mixed high forest and wet forest can, however, change into high forests with a low water table and into the poorest habitat forests with diminished timber increments.

The Influence of the Utilization of Old Open Pits as Coal Refuse and Ash Disposal on the Quality of Ground Waters

The growing tendency in the last few years to utilize old open pits for waste disposal had caused in 1973 large-scale research in all the most diverse aspects of this problem, and among them, in cooperation with EPA, investigations of its influence on ground water quality.

Included in the research were wastes from coal mines, washeries, and ashes and slags coming from coal-fired power plants. At the beginning, a system was developed to distinguish the basic groups of problems.

The first group of problems is concerned with the chemistry of wastes, considered from the viewpoint of their susceptibility to:

- Leaching out of the finest fractions, in the form of suspension, by waters infiltrating through the stored material,
- Dissolving of some components of the wastes and their washing out in the form of solutions.

The second group of problems relates to the influence of hydrogeological factors on the possible penetration of pollutants to underground waters. Among this group of problems, four main kinds of storage conditions can be named:

- Conditions when the storage basin is built of impermeable formations, such as clays or loams.
- Conditions when the ground water table lies below the bottom of the storage area, and penetration of pollutants takes place by infiltration of atmospheric waters through the dump and, subsequently, through an unsaturated bed of potentially permeable soils which separate the disposal bottom from the ground water table.

- Conditions when the ground water table in the pit has been lowered by natural or artificial drainage while the pit was vacant, and subsequently, as a result of dumping the water table, has risen leading to the saturation of the dumped material so that all the dump or part of it has found itself below the given ground water table level.
- Storage in water, i.e., in an old open pit composed of permeable soils, which, after stopping the mining work, has filled with water to the height of the regional ground water table.

The third group of problems includes the influence of hydrogeological factors on the possible migration of pollutants within beds containing ground water. Here, the following aspects of the problem require consideration:

- Propagation of pollutants in an aquifer where the migration factors are only represented by the forces of dispersion and diffusion, and those resulting from the difference in densities of the pure and polluted water,
- Permeability of the aquifer,
- Hydraulic gradient (slope of the table),
- Time,
- Inhomogeneity of geological structure (e.g., foldings, intercalations, etc.).

The fourth group includes problems of a physical and chemical nature which take place in the course of the migration of pollutants through the soil:

- Natural dilution of the polluted liquid in the mass of pure water saturating the aquifer,
- Absorption,
- Ion exchange between the liquid and the soil, and
- Other chemical reactions.

The fifth group includes problems of stability of the pollutants. This is a highly involved problem which practically could not be solved to the end. The stability of pollutants should be considered from the following viewpoints:

- Kind of pollutant,
- Rate of exchange of water in the ground water basin, being a function of the balance of recharged and drained-off waters,
- Geometrical, spatial relation among the pollution sources, recharge regions, and drainage of the basin.

The sixth group includes problems connected with the methods of artificial prevention of contacts that permit polluted waters to mix with pure ground water. The selection of suitable solutions and methods of action should be based on technical possibilities and on the technical and economic expediency.

As follows from the above general analysis, the formation and propagation of pollutants due to the storage of wastes from mines and power plants in open pits is a highly complex problem. It results from many different factors which cause the number of possible variants to be practically unlimited.

Nevertheless, it is possible to separate out the most essential factors and to introduce into practice certain rules, which will enable one to establish a proper location of disposal and the most suitable stacking methods, so that their influence can be kept to a minimum. This has been partially shown by recent research, the results of which were forwarded to EPA and which, owing to the limitation of time, cannot be reported in this paper but can be discussed if we wish.

Conclusions

The deep drainage impact of openpit mining on the ground water system can cause widespread changes in their quantitative and qualitative stage. However, if all the operations are preceded by proper investigation and exhaustive analysis, the effects can be predicted and proper means of environmental protection can be applied. Some of these means involve horizontal and vertical tight diaphragms and are under preliminary investigation.

HYDROLOGIC RESEARCH IN STRIP-MINED AREAS OF SOUTHEASTERN MONTANA

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Introduction

Concern for the environment has expanded during the 1970s to generate hydrologic and other types of research examining the effects of mining and development of coal. Objectives of hydrologic research in the Fort Union Coal Region (Figure 1) are to understand and predict the hydrologic effects of strip mining. Such understanding and predictive capability will enable applications of mining and reclamation techniques to minimize or eliminate development-related hydrologic problems.

Research has thus far established that the main hydrologic effects of strip mining of coal are changes in ground-water flow patterns during mining, and changes in ground-water quality after mining is completed. Alterations of flow patterns during the mining operations occur locally in aquifers peripheral to the mines. Alterations of ground-water quality occur within and down-gradient from mined and reclaimed areas.

The simple acknowledgment of hydrologic effects has little meaning without establishment of their significance. Objectives of this report are to describe the current status of research at mines near Colstrip and Decker (Figure 1), to add perspective to current knowledge, and to define the directions of the research program.

Colstrip

From 1924 through 1958, the Rosebud Mine (Figure 2) was operated by Northwestern Improvement Co. The relatively wide southeastern end of the mine has been developed by Western Energy Co. since 1968. Ground water in nearby aquifers flows into the mine area from the north and west. The undisturbed

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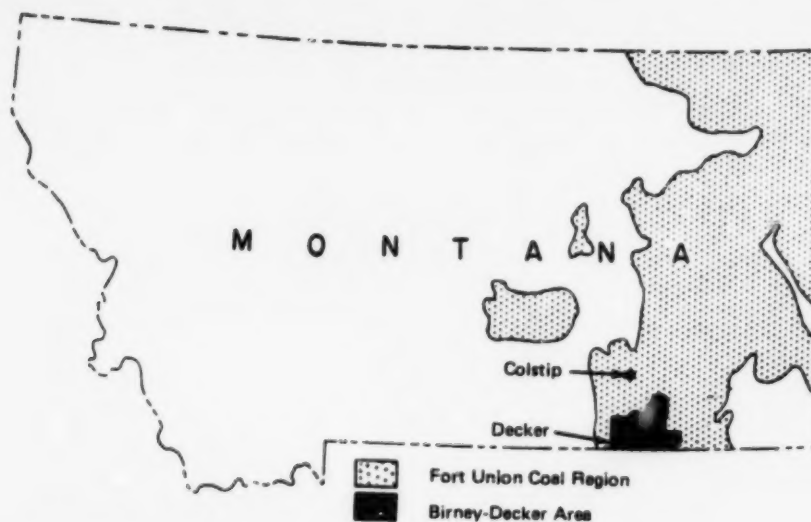


Figure 1. Locales of Fort Union Coal-Related Hydrologic Research in Montana.

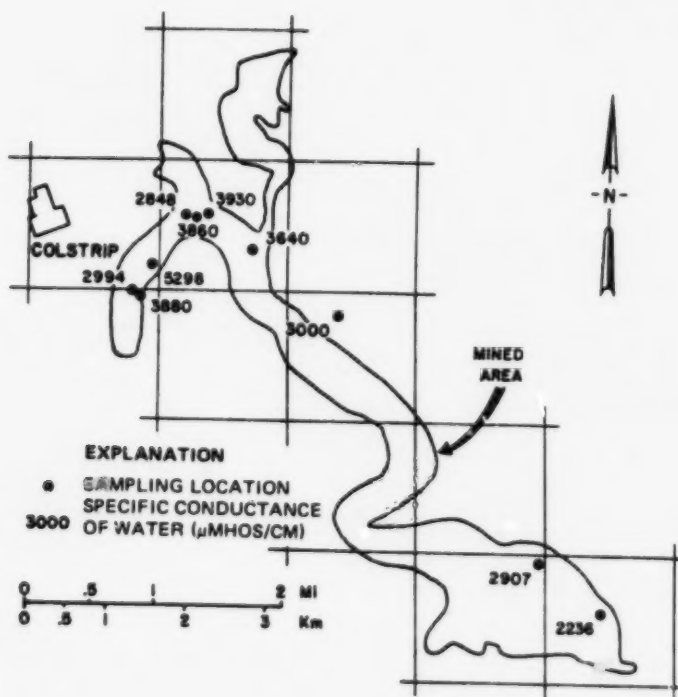


Figure 2. Specific-Conductance Values for Waters from Rosebud Mine Spoils, Southeastern Montana.

aquifers are beds of sub-bituminous coal and very-fine-grained sandstone that supply small yields, generally less than .5 l/s (liters per second), for livestock and household uses. Preliminary aquifer tests indicate that transmissivities of the aquifers are all less than about $12 \text{ m}^2/\text{d}$ (square meters per day). Entrance rates of waters to the mine are not great; there is no abundance of ground water in the backfilled areas or in the active mine pit.

Waters have been obtained for chemical analyses from wells established specifically to determine hydrological characteristics of spoils, and from ponds in portions of the backfilled area. Values shown in Figure 2 are specific-conductance values for waters from spoils; these values equal about .9 of the dissolved solids concentrations. Specific-conductance values of waters in the spoils range from about $2000 \mu\text{mhos}/\text{cm}$ (micromhos per centimeter) in the relatively young spoils in the southeastern corner of the mine, to more than $5000 \mu\text{mhos}/\text{cm}$ in the older spoils near Colstrip. The apparent relationship of more highly mineralized waters occurring in older spoils cannot yet be explained. Laboratory data thus far indicate little relationship between ages of spoils and the degrees of mineralization of waters within them (Pagenkopf, Whitworth, and Van Voast, 1975).

The mined area is so geologically complex that ground-water flow patterns within it have not yet been specifically established. Near the northwestern end of the mined area, where more mineralized waters apparently occur, correspondingly mineralized waters have been detected occasionally in a nearby stream during periods of extremely low or no flow. It is assumed that these waters have originated in Rosebud spoils and have migrated northwestward as ground water to the watercourse (Van Voast and Hedges, 1974). Similar waters have not been detected upstream from the mine area. In other streams down-gradient from the mined area, waters of abnormally high dissolved-solids concentrations have not been detected.

An overview of water quality for the Rosebud Mine and wells and springs in a large surrounding area (Figure 3) shows that water in the mine spoils is indeed generally more highly mineralized than waters from aquifers not disturbed by mining. Of the range of dissolved-solids and specific-conductance values for waters from unaffected aquifers, values for spoils waters correspond with the approximate upper half. However, only values for waters from the northwestern end of the mine greatly exceed most of those for the area.

Principal constituents in all waters analyzed from the spoils were calcium, magnesium, and sulfate. Waters from undisturbed aquifers are chemically similar to the waters in the spoils. Apparently, ground water entering the mine area is not altered in chemical type; if anything, the existing principal constituents in solution are increased. This relationship is compatible with the assumption that the quality of ground water is determined by the minerals available for dissolution, and that these minerals are more available for dissolution in the disturbed overburden materials than they are in the undisturbed strata.

Decker

Hydrologic studies at the Decker mine area (Figure 4) were begun in 1970 when a pre-mining study was completed and an observation network of 14 wells was established in and peripheral to the proposed mine area (Van Voast, 1974). Research there has provided much information about changes in water levels and

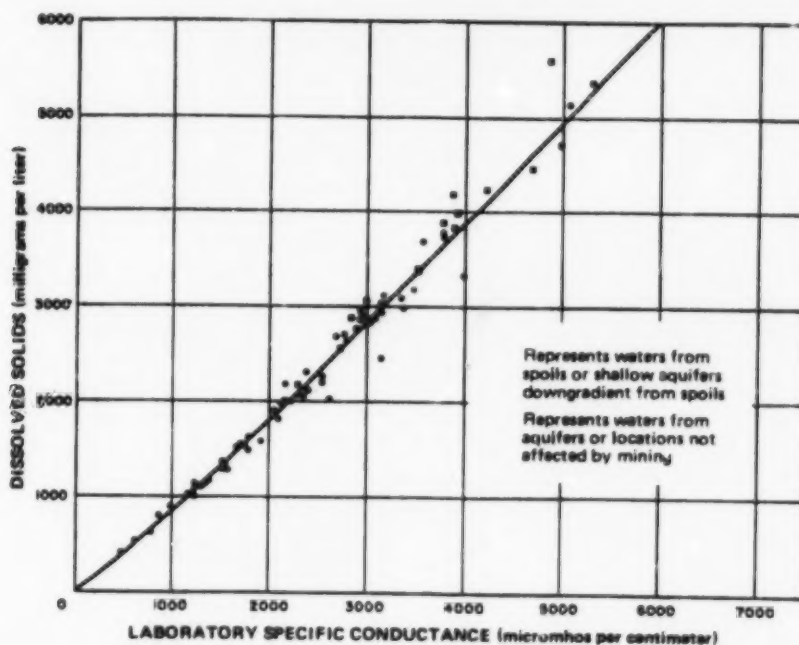


Figure 3. Plot of Laboratory Specific Conductance vs. Dissolved Solids for Waters Sampled Near Colstrip, Southeastern Montana.

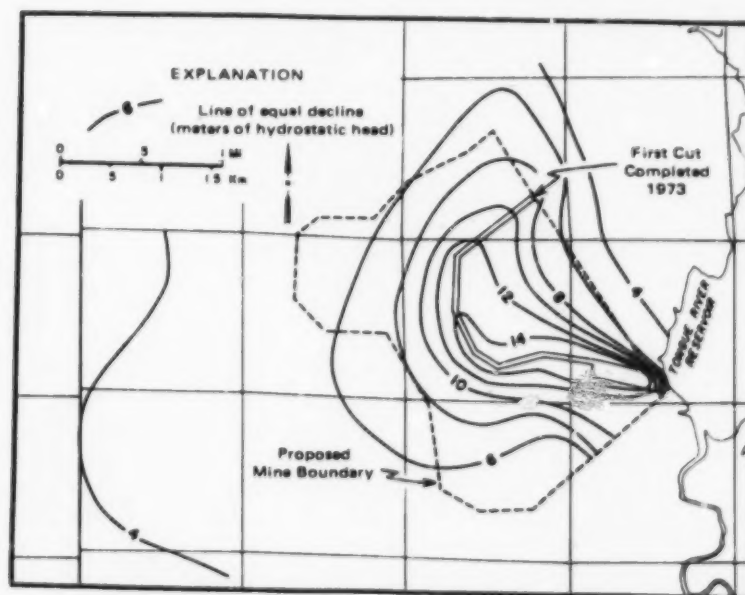


Figure 4. Piezometric Declines (D-1 Coal Aquifer) Near Decker Mine: January 1972 - January 1975.

pressure surfaces in an active mine situation but has not yet provided data on post-mining hydrologic conditions.

At the Decker Mine, a bed of sub-bituminous coal 15 meters thick is being removed. The coal bed is also a significant aquifer for the area. Similar to aquifers near Colstrip, this bed has transmissivities between about $9 \text{ m}^2/\text{d}$ and $12 \text{ m}^2/\text{d}$. Flow in the aquifer is eastward and northeastward from uplands to the watercourse of the Tongue River. The first cut of the mine intercepted this natural ground-water flow and began diverting it directly to the Tongue River Reservoir at the cut's easternmost end. Since mining began in 1972, the piezometric surface for the coal-bed aquifer has declined more than 4 meters within 3 kilometers west of the mine (Figure 4). Piezometric declines east of the mine are extremely localized because of recharge from the reservoir. North and south of the mine area the declines are restricted by outcrop and fault boundaries of the aquifer. Predicted impact of the piezometric declines is the eventual loss of water supplies at a maximum of 3 wells (Van Voast, 1974). Those water supplies can be replaced by wells drilled to deeper aquifers.

The underground waters intercepted by the mine cut and pumped directly to the river and reservoir are waters that have discharged naturally to the river long before mining began. These waters are now collected in a sump at the easternmost end of the mine and from there they are pumped to the watercourse. The sump is deep enough below the river that waters also enter from beneath the river's flood plain. The mine effluent is therefore a combination of waters from the coal-bed aquifer and waters from alluvium along the river.

When mining began in 1972, the mine effluent flowed at about 350,000 gallons per day (Van Voast, 1974) and consisted almost entirely of waters from the coal. Chemically the effluent was very similar to waters sampled from local wells (Figure 5). As mining proceeded, discharge from the coal-bed aquifer decreased gradually as hydrostatic pressures adjusted to new base levels established by the first mine cut. The amount of water being induced from the flood plain probably held relatively constant because of nearby recharge supplied by the river. The effect of the reduced volume of water from the coal-bed aquifer has been a reduction in the chemical constituents in the mine effluent. Since 1972, concentrations of chemical constituents in the effluent has decreased sporadically but continuously. A rough approximation of the changes in chemical concentrations is a 40 percent reduction in dissolved solids, bicarbonate, sodium, and sulfate. These findings directly negate one of the predictions published by the Montana Bureau of Mines and Geology (Van Voast, 1974). There, it was estimated that mine-effluent rates would gradually increase and finally be double the first year's rate. These chemical differences indicate that ground-water discharge from the coal to the mine must have decreased by at least 40 percent. There is no indication that this trend will not continue.

Minor chemical constituents in the mine effluent, such as calcium and magnesium, have varied sporadically through the period of mining with no apparent trend to increase or decrease. Calcium and magnesium have been found in concentrations between about 8 and 80 mg/l (milligrams per liter); in most analyses, magnesium has been present in slightly greater concentrations than calcium. The result of continuously decreasing sodium concentrations and non-corresponding changes in calcium and magnesium has been a strong decrease in SAR (sodium adsorption ratio) values (Figure 6). The SAR values have decreased by more than 50 percent since mining began. It first appeared that the waters would not be useable for irrigation during reclamation of the mine spoils. The SAR values have since reduced such that irrigation is probably feasible.

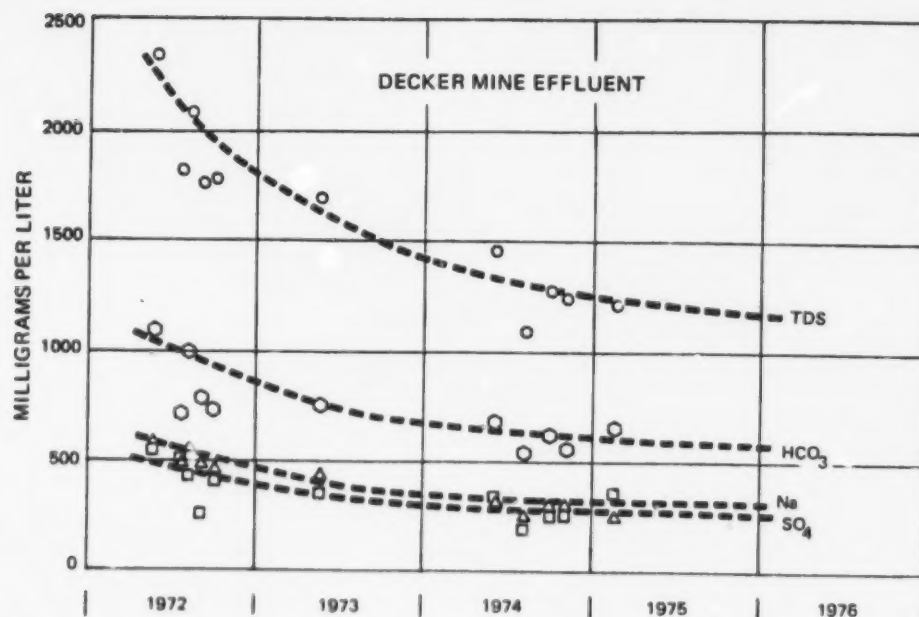


Figure 5. Concentrations of Total Solids and Selected Constituents in Decker Mine Effluent Since Mining Began.

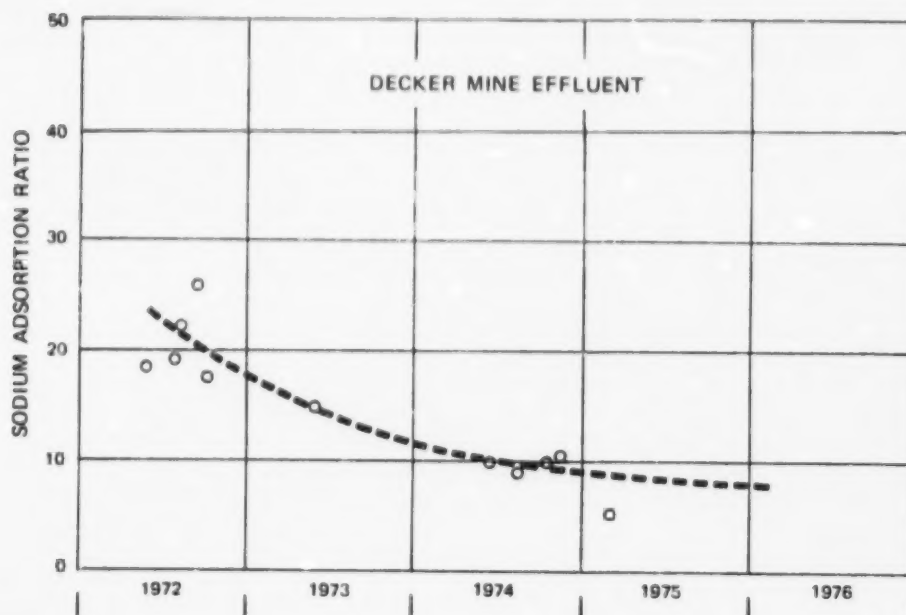


Figure 6. Sodium Adsorption Ratios Determined for Decker Mine Effluent Since Mining Began.

Another chemical constituent, nitrate, has occurred in sporadic concentrations in Decker mine effluent waters (Figure 7). The nitrate concentrations have varied from less than one mg/l to more than 110 mg/l. The average concentration discharged to the river is probably very low; most concentrations found have been less than 20 mg/l, and many less than 10 mg/l. The occurrence of these abnormally and sporadically high nitrate concentrations may be attributed to residual nitrates from explosives used in blasting overburden and coal or to highly soluble nitrate compounds in the disturbed materials. Similar anomalous concentrations of nitrate have been found occasionally in waters in the active pit of the Rosebud Mine.

Water-quality data made available through baseline collections by the U.S. Geological Survey (open-file report 74-371) enable a perspective of Decker mine effluent water relative to other ground waters of the Birney-Decker area. For example, of 231 samples obtained from wells and springs (Figure 8), about 90 percent had specific-conductance values greater than 1000 μ mhos/cm (micromhos per centimeter) and SAR values greater than 2. Specific-conductance values of about 70 percent of these waters, and SAR values for about 60 percent of the waters, were greater than those of the effluent (Feb. 2, 1975).

The Tongue River is a major ground-water discharge lineament in the Birney-Decker area and receives effluent from the undisturbed aquifers as well as the mine; chemical impact of the mine's effluent upon the river should cause no environmental concern.

When mining has been completed at Decker, waters of different chemical quality will begin entering the river and reservoir. The mine spoils will generate ground waters more highly mineralized than those of the pre-mining system. These waters will enter the river system at approximately the same rates as did waters before mining began. Two wells, very recently installed in Decker mine spoils, contain waters that may be chemically representative of post-mining conditions. Laboratory analyses of the waters have not yet been completed; field specific-conductance values of about 6000 μ mhos/cm indicate that dissolved-solids concentrations of the spoils waters will be about twice those of waters in the pre-mining system.

Laboratory Simulations

Predictions of post-mining water qualities will require laboratory simulations representative of field conditions. One way to develop and test this expertise is to conduct laboratory leach tests using spoils and overburden from mined areas in attempts to simulate chemistry of spoils waters obtained in the field. The method has been demonstrated with apparent success for mine spoils in Colorado (McWhorter, Skogerboe, and Skogerboe, 1974). In the Colorado research, distilled water was combined with spoils materials to produce saturated pastes. Waters extracted from the pastes were chemically comparable to field-collected spoils waters. In Montana, similar leach experiments have been attempted with overburden from the Decker and Rosebud mine areas (Figure 9). In this work, waters from local aquifers known to be discharging to the mines are utilized as solvents (Pagenkopf, Whitworth, and Van Voast, 1975). Saturated pastes seemingly do not simulate field conditions here, so projections must be made from leach experiments with spoils and water in different percentages of combination. Although the experiments have not yet provided conclusive results, some concepts are becoming evident. Relationships shown in figure 9 indicate that specific-conductance values of spoils

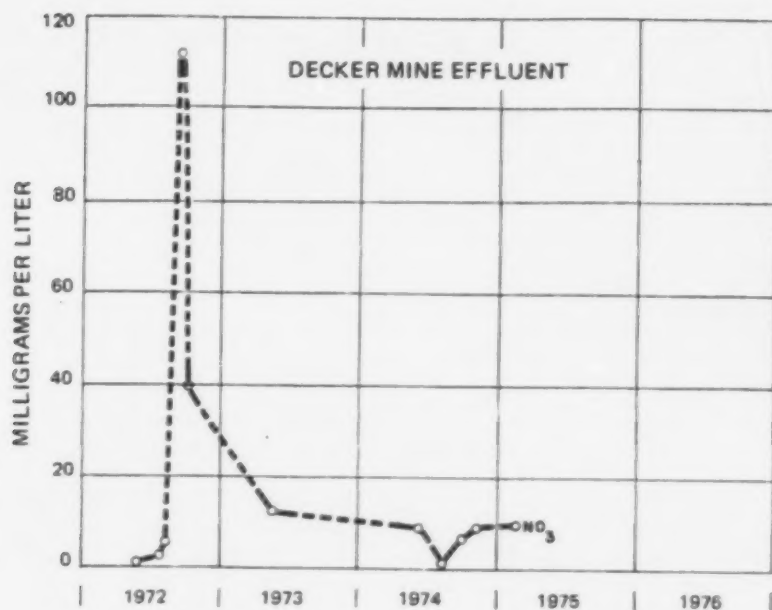


Figure 7. Concentrations of Nitrate in Decker Mine Effluent Since Mining Began.

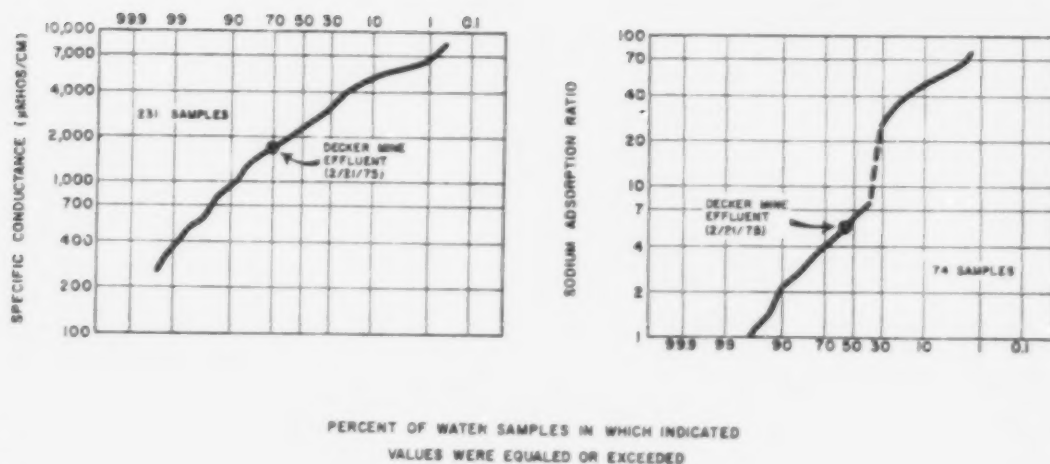


Figure 8. Statistical Distributions of Water-Quality Parameters for Samples of Ground Water from the Birney-Decker Area, Southeastern Montana.

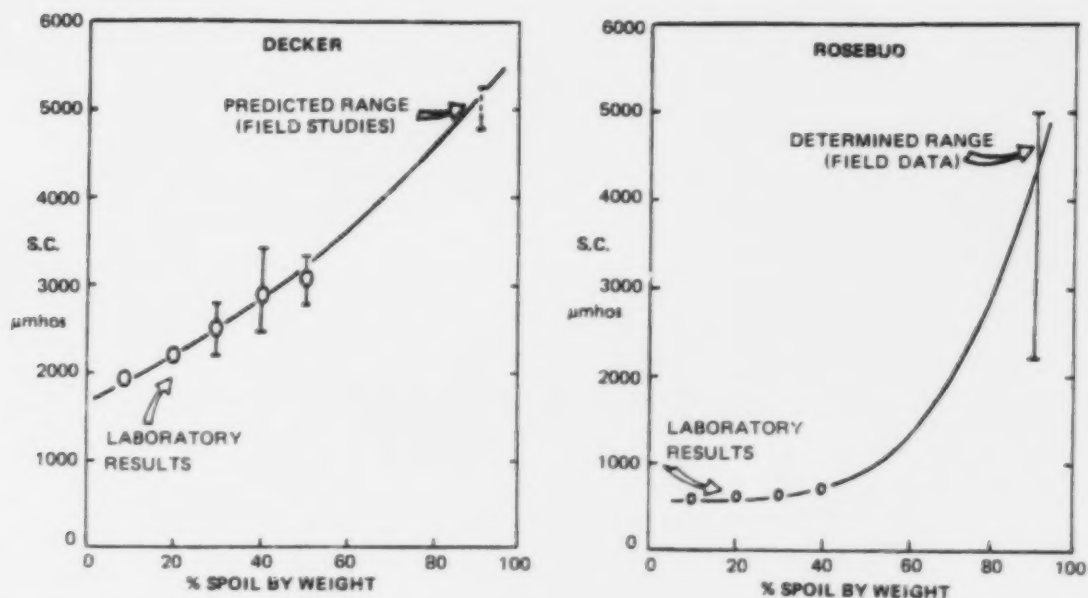


Figure 9. Projections of Laboratory-Produced Spoil-Leachate Conductances to Field Predictions and Determinations.

waters under field conditions (about 90 percent spoil and 10 percent water, by weight) can be estimated by projections of laboratory values. Another indication is that runoff from mined areas will not be highly mineralized because spoil-water ratios for runoff will be small.

A complication to the laboratory work is that spoils waters occur in the field under various degrees of mineralization. Laboratory projections will have to be directed toward chemical ranges rather than specific concentrations. To approach these ranges, many additional experiments are planned with larger numbers of overburden samples and more diverse spoil-to-water ratios.

Summary

The research that has been described in this report is only a portion of a larger and more comprehensive program. Studies have been initiated in three phases of the coal-development cycle (Figure 10). These are evaluations of pre-mining, mining, and post-mining hydrologic conditions. All approaches require similar data and are directed toward a common objective. That is the development of predictive capabilities as input for mine and reclamation planning.

Some of the studies that were initiated in areas before mining began have now evolved to studies of hydrologic conditions during mining. Some research that began during mining operations has evolved to research of post-mining conditions. The pre-mining and mining studies determine original and transitional conditions but require unreasonably long periods of time to generate

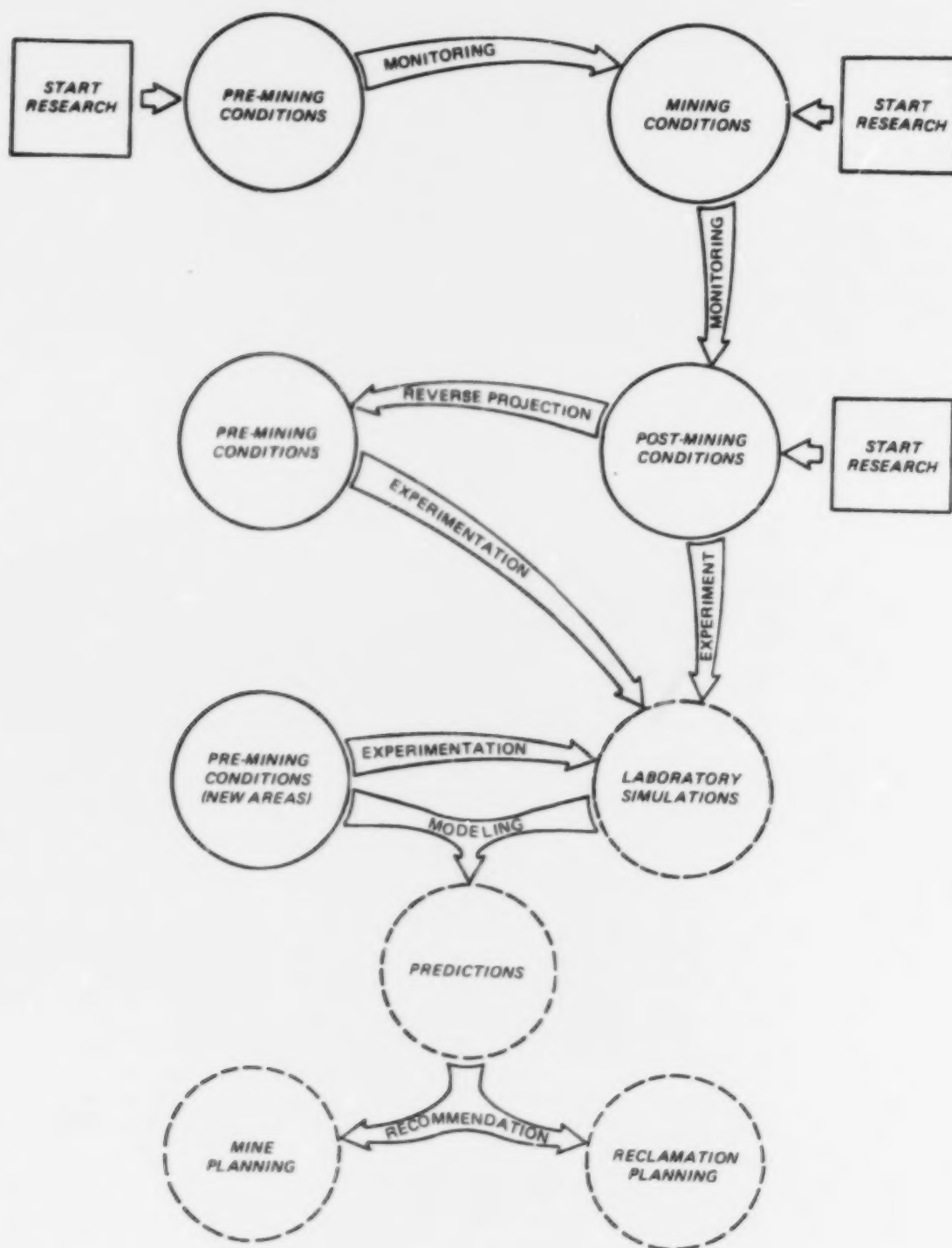


Figure 10. Coal-Related Hydrologic Research: Options, Directions, and Objectives.

post-mining data. To speed a satisfactory conclusion to the research, studies of areas already mined are now in progress.

With all three approaches to the problem, and with the development of simulation techniques, potential hydrologic effects of future mine operations will become predictable.

Acknowledgments

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PURIFICATION OF WATERS FROM STRIP
LIGNITE MINES

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"POLTEGOR"
Principal Investigator

Introduction

One of the substantial lines of influence of lignite openpit mines on the environment is the pollution of water in the flows and reservoirs which are the collectors of their drainage water.

The lignite deposits as a rule have considerable waterlogging, and their exploitation involves a constant carrying away of significant amounts of water, the quantity of which approaches $120\text{m}^3/\text{min.}$ per one mine. Depending upon the drainage methodology adopted, some 60-100 percent of the water volume can constitute the polluted water from an openpit excavation or active underground drainage excavations (galleries).

The quality of waters, which can be evacuated to the surface flows, is being controlled by some regulations. According to these regulations, all flows and surface reservoirs have been divided into three classes of purity. The class of water purity depends on a planned water assignment in a given flow.

In Class I are listed flows -- waters which are designed to supply the population with potable water, to supply industry requiring water of a drinking water quality, and also for use in salmon fish breeding.

In Class II belong the water flows -- waters which are designed for fish breeding, for the needs of animal husbandry, for arrangements of municipal swimming pools, and for water sport practices.

In Class III belong waters designed to supply the industries with water, with the exception of industries requiring pure water, and to irrigate agricultural regions utilized for garden cultivations.

The corresponding allowable levels of pollution were determined for waters belonging to particular classes of purity, which cannot be exceeded directly in downstream, below the mine, water outlets. Some of these parameters are given in Table 1.

One has to stress the fact that the permitted suspended matter level does not apply to periods of sudden water surges such as floods, for example.

The up-to-date regulations do not state precisely and clearly the permitted color and turbidity indices of the evacuated polluted waters and sewages, but we expect new regulations in which these features of water will be defined exactly.

Table 1.

O. n.	Kind of pollution	Concentra- tion UNIT	Class of purity		
			I	II	III
1.	Biochemical oxygen demand	mg O ₂ /l	4	8	12
2.	Permanganate oxygen consumption	mg O ₂ /l	10	20	30
3.	Chlorides	mg Cl/l	250	300	400
4.	Sulphates	mg SO ₄ /l	150	200	250
5.	Total hardness	mval/l	7	11	14
6.	Dissolved substances	mg/l	500	1,000	1,200
7.	General suspended matter	mg/l	20	30	50
8.	Reaction pH	-	6.5-8.0	6.5-9	6.0-9.0
9.	Total iron	mg Fe/l	1.0	1.5	2.0
10.	Manganese	mgr Mn/l	0.1	0.3	0.8
11.	Temperature	°C	22	26	26

Quality and Quantity of Waters Evacuated from the Lignite Openpit Mine

In the process of draining off the mines one can distinguish between conventionally named "pure," and "polluted waters" such as mine waters or sewages.

Pure waters are waters usually taken from a well system of drainage, and also sporadically from the underground gallery draining system during periods when no mining activities are conducted in these galleries. Such waters are, as a rule, deprived of suspended matter, are colorless, and have a chemical composition characteristic of underground waters in a given aquifer.

These waters are equivalent in their composition to the superficial water purity of the first class and are pumped directly to the receivers without being purified first. Polluted waters come from active underground galleries and from superficial draining of openpit excavations themselves. The chemical composition of such waters during periods when there is no atmospheric precipitation, approaches the composition corresponding to the ground waters, but differs when the rainfalls come.

Table 2 presents some of the parameters of the mine water pollutants in particular mines.

As it appears from the presented values, one can distinguish mainly two kinds of mine waters -- the ones from the mines in the Konin region and the other ones from the Turów region. Similar to the last ones are also waters from the Adamów mine. The waters from the Konin area belong to waters with

Table 2

O. Nr.	Kind of Pollution	Concentration Level	Turów I	Turów II	Adamów	Open Pit Patków	Konin Basin Open Pit Kazimierz	Open Pit Józwin
1.	Biochemical oxygen consumption	mg O ₂ /l	0.8-4.2	1.2-2.0	1-40	-	-	-
2.	Permanganate oxygen consumption	mg O ₂ /l	3-96/30/	22-160-60	64-390	8-52	10-55	-
3.	Chlorides	mg Cl/l	27-42	16-52	20-100	to 13	to 14	to 13
4.	Sulphates	mg SO ₄ /l	270-480	204-350	50-150	0-40	to 10	to 18
5.	Dissolved substances	mg/l	650-1050	560-100	to 400	270-365	to 360	to 600
6.	General suspended matter	mg/l	traces 1000	20-7200	60-2800	44-135	73-370	to 350
7.	Reaction pH	-	7.5-8.1	7.5-8.1	7.0-8.1	7.8-8.0	7.6-8.3	7.0-8.0
8.	Total iron	mg Fe/l	0.02-0.5	0.07-0.3	0.0-0.1	to 0.2	to 0.1	to 0.7
9.	Color	mg/l Pt	10-30	30-90	15-20	3-50	10-45	to 30
10.	Turbidity	mg/l SiO ₂	10-1000	imperv.	10 up to imperv.	5-50	30-50	10 up to imperv.

the lowest level of pollution, whereas waters from the Turów II indicate the highest physico-chemical pollution rates. One can state, in general, that the main and sometimes the only pollutant of mine waters, exceeding the permitted rates, is the quantity of suspended matter. The suspended matter constitutes fractions of sands, dusts, clays, loams, lignite--all of various shapes, dimensions and concentrations. The suspended matter has, therefore, various hydraulic and sedimentational characteristics.

The sizes of suspended particles vary from the colloids to the grains of medium and coarse granulations, and the shapes vary from the ones approaching the granules to the ones of sheetlike and needlelike shapes. The qualities and quantities of pollution in mine waters change both in hourly and in yearly intervals, depending on the mining, geological, and atmospheric conditions. The up-to-date research of this issue has not provided, as yet, any method for the prediction quantities of the suspended matter in mine waters of newly designed pits. Past and current observations and physico-chemical analyses of mine waters permit one to confirm, sometimes, the times of greater increase in the suspended matter concentration in waters coming from open pits after the rains set in.

Moreover the following was ascertained:

- A concentration of the suspended matter increases in autumn and spring;
- The concentration in the suspended matter increases proportionally to the surface of the slopes and lignite levels in the watershed; and
- Proportional dependence of the suspended matter concentrates on pit's bottom inclination and on the kind of geological formations appearing in the floor of the pit.

In designing an installation to purify dirty waters coming from the drainage of strip mines, it is important to have an accurate determination of an average flow value and also a reliable flow of waters derived from atmospheric precipitation. This last one is being computed as a precipitation runoff with a 10-50 percent probability of its occurrence. The values of an average inflow of polluted waters in m^3/min . change in particular mines from 20 to 120 m^3/min . Such values comprise solely quantities of dirty waters, which usually constitute around 60-100 percent of the total amount of waters being evacuated from the drainage. Presently, about 200 million m^3 of water on a yearly scale is evacuated from strip lignite mines drainage and resulting from this, waterlogging fluctuates from one to ten m^3 per ton of excavated coal. One expects that in the year 1980 the total quantity of evacuated waters may grow to about 400 million m^3/year , and in this amount the polluted waters will come to 200 million m^3/year . This is the result of the actual deep drainage tendency to use well methods which leads to a diminishing of the quantities of polluted waters. The waters evacuated from presently exploited mines are discharged to the surface receivers. More and more water deficiency, especially in the extensively industrialized areas, forces the treatment of waters coming from drainage as a source of water, especially required for cooling purposes in power plants built near the mines. The problem of purification, in this case, is connected with the simultaneous treatment of waters to the standards required, as ruled for cooling waters (which has to be characterized at least by quality of first class of purity mentioned above).

The Currently Employed Methods in the Mine Waters Purification

The purification of mine waters requires a reduction in the suspended matter of an order of 60-95 percent. The initial concentration in the mine waters in the Konin and Adamów regions amounts to 100-300 mg/l during periods without rainfalls, and is approaching 1,000 mg/l and more after the rainfalls.

The required concentration of suspended matter in waters evacuated to the receivers cannot exceed the value of 20-50 mg/l, which is relevant to the established classes of the receiver's purity. A reduction in the suspended matter, in current practice, took place in large field sedimentation basins, jointly occupying an area of about 60 ha.

In the years 1964-65, tests were carried out experimentally on water purification in the strip mine, Kazimierz, with the aid of hydrocyclones. The erected purification hydrocyclone plant worked for about two years. However, due to insufficient effects in the reduction, particularly, of particles creating the turbidity, and also because of some exploitational troubles, this technology was not widely used.

The typical parameters of the four largest sedimentation basins working on the lignite strip mines and the effects of their work have been compiled in Table 3.

The first settling basins constructed before 1960 had significant volumes and a long theoretical time of water retention, approaching sometimes five days as per the calculated average inflow. Later on, the sizes of the sedimentation basins gradually began to decrease, and simultaneously the effectiveness of their operation rose. This was possible as a result of the improvement in their shape, water discharge, and flow way. Now, the basis for a dimensioning of a sedimentation basin is a 24 hour time period of retention of a medium inflow, and the hydraulic load of about $1-1.2 \text{ m}^3/\text{m}^2$ per day.

During the latest field investigations, the results of which are now being introduced into practice, it was ascertained that in large basins the basic sedimentation process was being performed on an area constituting 30-40 percent of the total sedimentation basin surface, and the actual time of retention was sometimes two to four times less than the theoretical time. This shows the low coefficient of a basin utilization and a small percentage of a piston flow of water through the settling basin. Such a condition was being caused by several factors such as the direction and speed of winds, kinds of water inflows and outflows, the geometric dimensions and shape of the settling basin, vegetation occurrence, the shape of a bottom and a number of other factors, which to a greater or lesser extent disturbed the piston flow.

Under consideration now is a further reduction in the size of the settling basins and of the time of the retention to 16 hours, and the increase of a hydraulic load to $2.0 \text{ m}^3/\text{m}^2$ per day by an accompanying time increase in the settling basins utilized capacity and the improved effects of its operation. This requires changes to be effected in both the shape and the dimensions, the manner of water inflow and outflow, and an application of procedures designed to eliminate the idle movement of water caused by a wind.

Table 3. The Characteristic Parameters of the Four Biggest Sedimentation Basins Operating Presently on the Openpit Lignite Mines and the Effects of their Work.

o. Nr.	The Name of the Sedimentation Basin and the Year of its Construction	Mines from which the Waters are Purified in the Sedimentation Basins	Average Inflow	Sedimentation Basins Surface	Present Capacity of the Sedimentation Basin	Average Depth	Theoretical Time of Retention	Suspension Concentration on the Inflow	Suspension Concentration on the Outflow	Average Percentage of Reduction
			m ³ /min.	Ha	Thousand m ³	m	Days	mg/l	mg/l	%
1.	Struga Biskupia 1960	Patnow	20	10	123 + 126	2.50	4.3	60-120	20	67-84
2.	Row Główny 1967	Patnow/Joswin	98	21.1	210	1.00 ^{x/}	1.5	100-200	30-60	65-70
3.	Teleszyna 1968	Adamow	17	7.8	170	2.20	7	180-250	10-20	90-95
4.	Sed. Basin near the shaft nr. 3 1969	Kazimierz	20	6.0	87	1.45	1.5	359	33	92

^{x/} Provisional depth, final one will be about 2.20 m.

The Direction of Completed, Up-To-Date Research Work in the Lignite Mine Waters Purification

The up-to-date performed research work was carried out in three main directions:

1. To learn in detail the physico-chemical composition and the properties of waters and suspension materials.
2. To elaborate the most effective technology of purification.
3. To learn the effects of the evacuated waters on the physicobiochemical parameters of the superficial receivers.

Research of a hydraulic and technological character was carried out in three typical field sedimentation basins:

1. The "Rów Główny"
2. The "Teleszyna"
3. The "Struga Biskupia"

The main purpose of these investigations was to establish the relationship between the hydraulic load and the time of water retention in the existing sedimentation basins, and the purification effect.

The methodology of research was based on a determination, with the aid of isotope tracers (Br. 82), of the real times of flow through the whole basin and of the demarcated cross-sections in it, with a simultaneous determination of the suspended matter quantities in these cross-sections.

Until now, the complete investigations were accomplished in only two first basins. The distribution of the suspension concentrations and the times of the inflow of the marked wave to the particular measured cross-sections in the sedimentation basin, "Rów Główny," are shown in Figure 1, whereas the ones from "Teleszyna" are shown in Figure 2. The diagram of the flow wave through the particular sedimentation basins is shown in Figure 3.

The investigations discussed above resulted in a reduction in the surface area occupied by the basins, by some 20-30 percent with the purification effect to about 30 mg of the suspended matter per one liter of water.

This, however, is not satisfactory, especially in view of the expected introduction in 1975 or 1976 of more stringent standards regarding the quality of waters evacuated to the superficial flows.

The Current Directions of Research Work

The construction of new lignite mines, characterized by large water discharge and more stringent purity requirements for waters evacuated from the open pits, and additionally the complex water management in mining and power plants are forcing the increase in the effectiveness of mine waters purification. This must not be accomplished through an increase in the surface areas of the purifying installation terrains, but has to go in the direction of improved efficiency of these purifying installations. Otherwise, in a relatively short period of time, one would have to take over an additional 100-120 ha of good land for the construction of sedimentation basins for forthcoming open pits and about 35 ha for the construction of additional new basins for existing mines. This requires the employment of new technologies of water purification, which should be based on a simple process, and installations, cheap in exploitation, which should warrant the level of water purification from suspension to one below 20 or sometimes 30 mg/l, independently of polluted water quality and atmospheric conditions (winds).

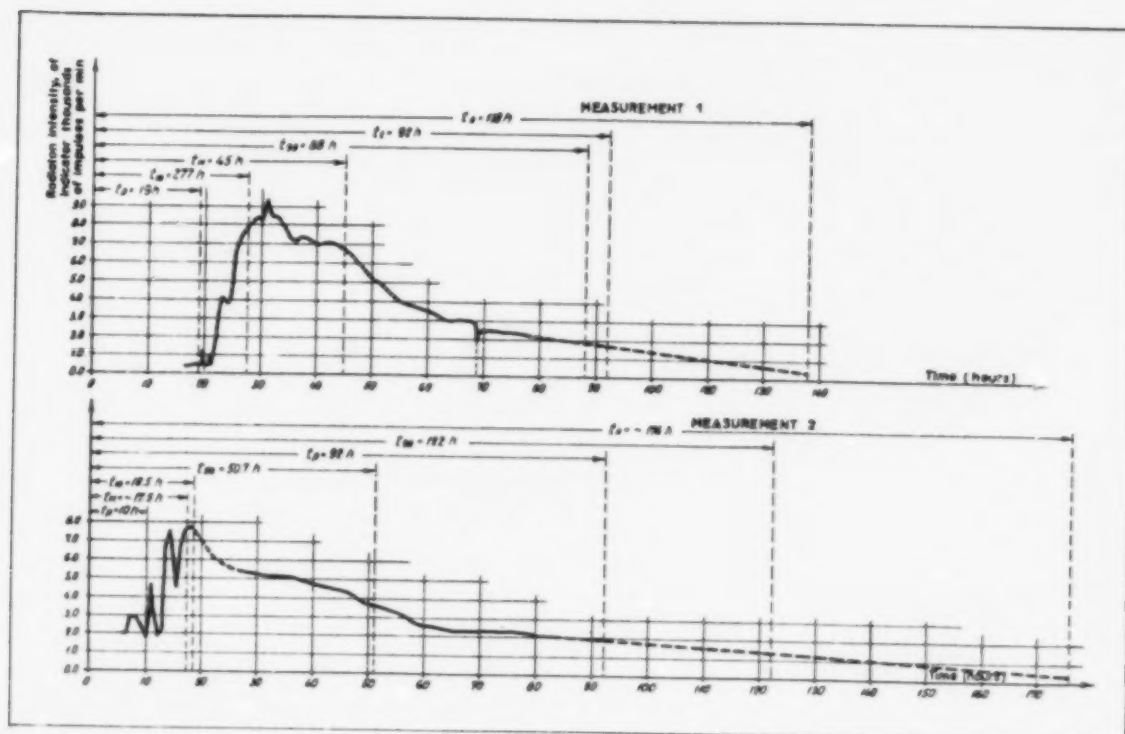


Figure 3. Flow Wave in the Rów Główny Sedimentation Basin.

For this reason, the following program was started:

1. Investigations of the radiation effect on the suspended matter sedimentation in mine water.
2. Investigation of synthetic flocculants effect as the basic coagulants in the coagulation process of the suspended matter in mine waters.
3. Investigations of usability of simultaneous coagulation and flocculation in purification of waters--in cases where waters are difficult to purify.

The first two subjects involve research cooperation with the E.P.A. and are under study.

We intend to conduct further hydraulic and technological research in the existing sedimentation basins.

The preliminary research, on a small laboratory scale, of the application of radiation in the process of mine water purification, carried out in 1972, gave a positive result. In the irradiated water samples the reduction in suspensions and turbidity was considerably faster, and the purification effect much greater. In laboratory conditions, such a reduction after two hours of sedimentation of the irradiated water approached a 94 percent level.

Also, the initial investigation of the Kationic type flocculants, a product of U.S.A., applied as the basic coagulant, gave excellent results in

the turbidity, suspension, and permanganate value reduction in polluted waters from the Adamów mine drainage.

Further research will enable an exact specification of the application possibilities of these methods in practice. For this research, a special sedimentation basin of 60 x 15 x 2 meters in size is under construction. Moreover, research is planned on the effects of a compact vegetation filter composed of water and mud, a so-called "vegetation filter," on the reduction of suspended matter, turbidity and color in the mine waters. It was observed that such a filter greatly aids the reduction of mine waters pollution.

Conclusions

1. A basic, and often the only, water pollutant of water derived from the Polish lignite strip mines drainage is the suspended matter and ensuing through it turbidity and color of water. The concentration of suspensions and their sedimentation properties indicate a significant variability both in the daily and yearly ranges (up to 7,000 mg/l).
2. Until now, employed methods of water purification have been based on a gravitational sedimentation process and partly on a spontaneous coagulation in large sedimentation basins, with their retention times of inflow from one to five days (the last figure for old operations).
3. The up-to-date purification methods permit one to obtain suspension reductions within the 60-95 percent range and their concentration on the outlet from the sedimentation basin, around 30-50 mg/l.
4. In connection with the more stringent restrictions regarding the permitted norms of pollution in waters evacuated to surficial receivers, it will be necessary to increase the effectiveness of water purification to achieve suspended matter concentrations below the 20 to 30 mg/l level.

Simultaneously, the new methods will assure a reduction in the area of the sedimentation basins and limit the resulting devastated regions. One has to expect that the work carried out in cooperation with the E.P.A. will be conducive to a wide application in the practice of these methods within the next three years.

REFUSE BANK RUN-OFF, ITS CHARACTERISTICS AND DISPOSAL

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Introduction

Coal preparation facilities throughout the United States generated approximately 96,000,000 tons of refuse in 1974. Of that total quantity of refuse an estimated 11,500,000 tons of coal tailings or slimes required disposal, generally through the use of tailings impoundments.

Water pollution can result from the run-off of dams, refuse piles, coal preparation plants, and non-point discharges from plant-site surfaces. This pollution can be either dissolved matter, suspended minerals or both. In this brief paper, suggestions for the prevention and solution of this source of water contamination will be presented.

Sources of Run-Off

Run-off usually takes place following periods of precipitation in the area of the coal preparation plant refuse pile. Run-off may also originate from accidental overflow of the preparation plant water clarification circuit. In some cases, old refuse piles were laid down on water seeps, springs or on terrain which is a natural water course. In any event, the chemical and physical nature of run-off is influenced by the coal seam being mined, type of mineral preparation process being used, the climate, and refuse handling practices at the mine. Since coal refuse banks are the waste product of the coal preparation process, a review of recent Environmental Protection Agency (EPA) findings which follow may be useful.

Coal Preparation

Water pollution problems associated with coal cleaning processes are of two general types: 1) contamination of plant process waters and 2) pollution of surface run-off in the vicinity of plant facilities and refuse disposal areas. Coal preparation pollution control technology is therefore divided into two major categories -- process water treatment and surface water control techniques. With proper management and planning, water pollution resulting from the preparation of coal can be minimized. Water treatment and control technologies are usually interdependent in the coal preparation process, and therefore will be discussed together.

Process Water Treatment

Fine coal and mineral particles, such as clays, remain suspended in plant waters resulting in potentially serious pollution from some coal cleaning facilities. Clarification techniques available for removal of these suspended solids include thickeners, flocculation, settling, vacuum filtration and pressure filtration. A typical closed circuit washery could incorporate thickeners or settling ponds with the addition of flocculation reagents to enhance settling of particulate matter. Coal fines separated from plant waters can either be blended with clean coal or transported to a refuse disposal site.

Froth flotation is a unit operation in coal cleaning that provides separation of fine coal from refuse and fine clay. Past industry practices limited froth flotation use to metallurgical grade coals because the additional preparation costs could not be justified with the low selling prices of utility coal. However, present market conditions are stimulating more operators to employ froth flotation cells for recovery of a saleable product from coal slimes. The refuse and fine clays segregated by flotation are then removed from plant waters via thickeners and filters. This provides an economic method for effecting water clarification.

In addition to removal of suspended solids, washery waters may also require treatment to control chemical parameters, such as pH, iron, sulfates, etc. Such treatment when required, is relatively simple, and is tied to the maintenance of efficient plant operation, acceptable product quality, and minimal pollution-related stress on equipment. Where chemical treatment is required, the most common practice is addition of lime to make-up waters, but treatment can also be performed prior to recycle of waters from settling ponds. As a final resort, process waters may require circulation through existing mine drainage treatment facilities. This particular water control practice is not common among existing preparation plants and should only be considered for extremely poor quality process waters.

A host of stringent Federal and State regulations have been promulgated or proposed regarding the control and management of refuse and tailings disposal. Emphasis of the regulations is directed toward coal operations conducted in the Appalachian region. Such regulations with respect to tailings impoundments lend a very high degree of difficulty in maintaining the continued use of tailings impoundments from now on into the future. There is a growing concern in the mining industry over proposed legislation for water quality standards from preparation plants. The biggest concern is the fact that all water circuits may have to be closed. No discharge of process water will be allowed.

Alternatives to the use of tailings impoundments require study, research and application of other systems regarding refuse tailings dewatering. Techniques available for dewatering this slurry are:

1. Mechanical Dewatering
2. Thermal Dewatering (Drying)
3. In Situ Dewatering
4. Chemical and Cementation Solidification including spherical agglomeration and/or pelletizing
5. Underground Disposal
6. Self Incineration

Each alternative offers mechanical operating advantages and disadvantages along with operating and capital cost considerations.

Change in Water Quality During Coal Preparation

Fine coal and mineral particles, such as clays, remain suspended in most plant waters. These particles vary in size from 28-mesh to colloidal dimensions, and most of them can be eliminated by thickeners, cyclones, and filters. Nearly all new washeries are designed to operate on a closed circuit. Various methods of water clarification applied to slurry and froth flotation tailings are flocculation, thickeners, settling ponds, vacuum filtration, and pressure filtration, among others.

The action of dissolved minerals or salts and various promoting agents that are added to enhance flotation, flocculation, and filtration significantly affect the properties of water. Run-of-mine coal contains varying amounts of minerals and soluble salts. Spunk and O'Donnell stated that the most common minerals in coal were allamite, pyrite, calcite, quartz and siderite, supplemented by clays consisting mostly of hydrosilicates of aluminum.

Some minerals and salts such as chlorides and sulfates of the alkalies and the alkaline earth metals dissolve easily in water. In certain circumstances the salts will significantly change the pH of the circulating water. For example, calcite, aragonite, and dolomite are slightly soluble to the extent of 14 parts per million in pure water at 25 degrees C. The influence of additional salts present in solution increases the solubility of the carbonates. Thus, sodium chloride, in concentrations up to seven percent by weight, can increase the solubility of calcite by 3.8 grams per liter. However, if the water contains carbon dioxide, or if any additional acid is present, the carbonate will neutralize the acid to a value proportional to its concentration. Soluble clays may also exhibit basic properties. It is conceivable for pyrite, marcasite, and other sulfides that are normally insoluble in water to oxidize and form ferrous sulfate and sulfuric acid. Iron sulfate is sometimes used as an agent to promote the action of flocculent electrolytes. The addition of salts, through either artificial or natural means, will increase the conductivity of the solution. Brunard and others found that the hardness of the wash water decreases in some European preparation plants with the chlorides, sulfates, and conductivity increase.

The rapid increase in froth flotation has introduced a new aspect to water treatment requirements. Methods presently in use for preparing fine coal do an acceptable job down to 48-mesh or 100-mesh.

Coal Refuse Production

A study of the geologic formation of coal is the first step in understanding the composition of refuse and in handling the drainage from coal wastes. Swamps of the Mesozoic and Paleozoic eras account for most of the Earth's coal reserves. Vegetable material falls into the swamp, is protected from immediate decay by the high water table, and begins to accumulate and form a peat bog. Natural acidity in the vegetation is probably responsible in part for the depressed rate of biological decomposition. In the absence of erosive forces, the bogs are filled, eventually covered by protective layers of sediment, and slowly converted to lignite, bituminous, and anthracite coals.

The conditions required for coal formation are: an interior or coastal swamp environment, little erosion, rapid deposition of material, and subsidence of subsequent flooding to allow further deposition and covering. Considering

this type of formation, one can easily visualize layers of silt and other foreign matter periodically flooding into the swamp, covering the vegetable material, and eventually forming partings in the fully developed coal seam.

The vegetable material carries with it various minerals and trace metals accumulated during the growth process. Among these constituents is organic sulphur derived from the swamp water. Studies show that sulphur and pyrite are present in modern peat deposits, as they must have been in the geologic past.

Nature and Formation of Coal Mine Drainage

The nature of acid mine drainage whether from the mine itself or from refuse pile run-off, varies from site to site. The nature of the dissolved salts and their concentration determine the usefulness of this water for make-up purposes. Several typical mine water analyses are listed in the table below:

Chemical Analyses of Water at Mine Sites

	Marianna (Pa.) #58	(C.Pa.) Penfield	(N.E. Pa.) Loomis	W.Pa. P8	N.W. Va. (W1)
<u>pH</u>					
lab	2.65	2.52	2.85	3.5	3.0
<u>Iron</u>					
Total Iron, lab	1348	630	1011	175	2940
<u>Acidity, ppm CaCO₃</u>					
Total	5820	2185	138.6	1300	6940
<u>Alkalinity</u>					
Mn, ppm	70	25	40	9.1	70
Al, ppm	595	108	26	40	220
Ca, ppm	1263	323	674	--	360
Mg, ppm	16	0	61	--	680
SO ₄ ⁼ , ppm	12838	3008	6493	1485	9650

Virtually all coal contains pyrites of varying amounts. This iron-sulfide mineral, when exposed to air and water in the course of mining is oxidized to ferrous sulfate. This salt in most cases leads to the formation of acidic iron-bearing water when dissolved in water. In a few instances, "ferrous bicarbonate" is formed and an alkaline iron-bearing water is produced.

Pollution of mine water cannot be completely prevented since presently there is no reasonably practical method of eliminating mine water. One of the serious difficulties is the wide variation in both composition and volume

which occurs not only between different mine water in the same coal field but also in the same water. Some mine water is excellent in quality and is taken by water companies and used for domestic and industrial purposes. Others are less pure and innocuous and are suitable only for industrial purposes. In some localities mine water can be found which contains acid and appreciable quantities of iron and is highly saline and contains excessive amounts of suspended solids.

Treatment of Mine Water

There are various methods for water clarification. These are applied to slurry or froth flotation tailings, singularly or in combination with one or two of several methods including flocculation, concentration, vacuum filtration and pressure filtration.

It might be mentioned that there are large quantities of rain water, such as run-off from roofs and roadways, at collieries which are discharged to sewers. At some collieries surface drainage is salvaged for use in the coal preparation plant. Where water shortages exist, it is advantageous to segregate surface drainage from the sewage system and provide storage facilities. After settlement or other treatment, the water can be used as a supply of industrial water for cooling purposes, boiler feed, and as make-up water for the main industrial supply.

Of the many treatment techniques for acid mine drainage, the most technically sound and economically feasible method at present involves lime-neutralization and aeration followed by preparation plant usage. Much recent work has been devoted to this technology and to the development of engineering parameters for widespread industrial application. With pollution abatement laws, in addition to the recurring drought and water shortages in coal producing areas, consideration is being given to the treatment and reuse of mine drainage as make-up water for preparation plants and as potential feed water to industrial and domestic supplies.

The whole array of alkalies has been examined and the lowest cost alkali available is calcium hydroxide.

Realistic cost estimates are available for lime-neutralization plants. A minimum of data is required and reliable approximations can be made quickly. Add to the calculated lime required for acid neutralization a 25 to 50 percent excess above the theoretical amount and multiply the total weight by the cost of lime. The range of lime consumption varies from eight to 15 percent with 10 percent of the total cost being the lime cost for the average plant. These approximations will give the highest probable cost and are easily verified. In general, the higher the electrolyte and the iron content, the lower the treatment cost per ton of iron removed. The lower the iron and the electrolyte content, the higher the cost per ton of iron removed. The costs consist of capital costs being amortized over ten years at six percent interest, plus all operating costs.

It should be pointed out that the lime estimation procedure derived through the above will give the highest probable cost. The cost can be reduced if it is possible to utilize ponds or other topographical features which will reduce the cost of settling areas. The costs outlined above will be further reduced by 50 percent if lagoons are already available. A useful consideration in making volume approximations is that the amount of consolidation, not the free-settling rate, is the important criterion for sludge settling.

Coal Refuse

The Pennsylvania regulations concerning coal refuse disposal areas require that slopes be limited to prevent ignition. Compacting, layering, and covering requirements state that slopes shall be nine degrees or less, unless special plans are implemented to stabilize the surface. In any case, 18 degrees is the limit. The regulations in Indiana pertaining to refuse from surface operations require burial of all waste materials. Burial eliminates the three problems of air infiltration and oxidation, erosion and run-off.

For stabilization and control of the refuse pile, it is necessary to compact the material as it is placed. This reduces the air voids, increases the bearing capacity, and reduces the possibility of slides and failures due to excessive water content. To aid in halting the movement of oxygen, a sealant (such as plastic, cementing agents, clay) can be placed over the pile. Good vegetation on a refuse bank further aids in trapping oxygen, because the humus that develops forms a moisture barrier in addition to demanding oxygen itself. In certain instances it may prove feasible to seal only the sides of a compacted pile, thereby cutting off most of its oxygen supply. Various research projects are currently investigating a host of surface sealants, including gypsum, wood chips, fly ash, waste cement, and various types of vegetation and earth materials.

The sealing techniques mentioned above are also effective in reducing the amount of infiltration and subsequent leaching from refuse material. Current theories maintain that most acid production is limited to the outside layer of waste; but, once produced, this acid water can infiltrate the pile and be stored, to reappear in the dry weather as an acid spring or seep.

Size Consist of Refuse

The particle size of the refuse should permit compaction. There must be a sufficient quantity of intermediate and small particle sizes so that the application of compaction forces will consolidate the refuse into a relatively solid and impervious mass. This requires that large refuse particles in great quantities be crushed before disposal. It should be noted that even highly reactive refuse can be adequately prepared by crushing into a very fine size and disposing of without further precaution.

Refuse Disposal of Fine Solids in Small Operations

One of the principal problems with waste associated from coal preparation plants may arise from the color and the fine solids contained in the unsettled effluent wastes. The problems of the disposal of coarse coal refuse have just been discussed, but little in common is observed between the two approaches for a solution. The color and the fine solids can be removed from plant effluents by employing cyclones, thickeners, and final settling basins to remove the fine solids and clarify the water. In many cases these installations circulate wash water, thereby minimizing the quantity that must be discharged. The uncirculated waste water, in most cases, is settled in earth basins before being discharged.

Untreated wastes from coal preparation plants are characterized by a heavy concentration of suspended solids and a dark black color.

Effluents from coal preparation plants add black color and significantly increase the suspended solids contained in the water. If the bottom organisms upon which fish live are covered, then it can be detrimental to water life by restricting the food supply. Further, the solids can restrict the natural development of water-life eggs laid at the bottom of the stream. Acceptable methods are available for removing fines from preparation plant effluent.

Refuse Disposal Areas

The refuse sites vary considerably in composition and size. They may be as small as an acre or as large as hundreds of acres. They vary from 20 feet to 200 or 300 feet in height. The amount of refuse at a site varies from a few tons to millions of tons. The refuse sites may burn only for a short time while others may burn for many years. Some refuse sites in the anthracite coal region have been burning for more than 50 years.

Because of mechanical mining and modern coal preparation, there has been a steady increase in the relative amount of coal refuse produced per ton of coal. At the present time it is estimated that as much as 1/4 of raw coal production may be discarded as refuse. In some cases it is as little as a few percent to more than 40 percent in operations where quality is critical. Coal refuse, varying widely in composition and size, is a function of the seam mined, the mining system, and the preparation system.

In designing and engineering coal refuse sites, several major considerations are important, including the selection and preparation of the refuse site, geometry of the refuse material, disposal practices, particle size of the refuse, maintenance of the piled material, and controlling a refuse fire. The new MESA regulations must be carefully adhered to in designing future refuse disposal sites.

The Refuse Site

To reduce transportation costs, the refuse site should be near the coal preparation plant. Transportation costs, land costs, topography, and zoning restrictions limit the selection of an area. A flat, gently-sloping site, or a gently sloping site through a narrow valley is satisfactory. If available, a hollow or valley is an excellent area. A valley will permit the filling from one hillside to another, limiting the number of exposed areas. Steep hillsides are usually not satisfactory, and, when used, extra site preparation and disposal costs are experienced. The foundation of the disposal area should be stable to prevent shifting and cracking and should be impervious to flow. Drainage is most important and should be provided so that watershed areas are not drained over, under, or around the refuse pile. Vegetation should be stripped from the land before refuse is disposed upon the area. An additional strip of cleared vegetation should be used to insulate the refuse material from the growing vegetation. This will reduce the incidence of kindling ignitions from debris and accidental brush-fire ignitions.

Geometry of Refuse Area

A minimum of surface area exposed to the atmosphere should be achieved. This will result in the minimization or restriction of spurs, fingers, and other narrow appendages. Drainage of surface water from the site should be prevented since erosion and slippage of refuse may occur. The eventual extent and volume of the refuse area should be determined initially, and this should be strictly adhered to over the years. Further, the mixing of older and fresh refuse should be avoided and restricted.

Disposal Procedures

Refuse should be permitted to have the maximum possible weathering period for oxidation and dissipation of the generated heat before being placed permanently. Weathering amounts of truck-load size are ideal for this purpose. The site and the reactivity of the refuse determine the actual disposal practice. Low reactivity refuse can be satisfactorily disposed of in layers which are thoroughly compacted by mobile equipment. More reactive refuse may require that the exposed edges be sealed with a substantial seal of impervious material such as clay. Highly reactive refuse may require a layer of impervious material between each of the refuse layers in addition to an impervious seal at the edges. High, steep grades that are unstable even on compacted refuse must be avoided. The edge can be contoured at such a slope that it can be negotiated by a bulldozer and compacting equipment. Where it is necessary to have an exposed pile face, it should be compacted and successive layers stepped back from the edge so that a saw-tooth effect is achieved rather than a steep, straight face.

Normal truck, scraper, or dozer traffic is effective in compacting the layers of coal refuse. For maximum compaction of highly reactive refuse, rollers can be employed, followed by a seal or inert material, before a second layer of refuse is applied. Coal refuse that is not sufficiently compacted will absorb air and subsequent oxidation will result in a rapid temperature rise which increases the absorption rate of oxygen. A chimney effect results which increases the circulation of oxygen through the refuse material.

Surface Water Control

Pollution control technology related to preparation plants and refuse disposal sites is generally aimed at prevention of contamination of surface waters (streams impoundments and surface run-off). Solicitous planning of refuse disposal is a prime control method. Disposal sites are isolated from surface flows and impoundments to minimize pollution potential. In addition, the following techniques are practiced to prevent water pollution:

1. Construction of a clay liner beneath the planned refuse disposal area to prevent infiltration of surface waters (precipitation) into the ground-water system.
2. Compaction of refuse to reduce infiltration and help prevent spontaneous combustion.
3. Maintenance of a uniformly sized refuse to insure good compaction (may require additional crushing).

4. Following achievement of the desired refuse depth, construction of a clay liner over the material to minimize infiltration. This is usually succeeded by placement of topsoil and seeding to establish a vegetative cover for erosion protection and run-off control.
5. Excavation of diversion ditches surrounding the refuse disposal site to exclude surface run-off from the area. These ditches can also be used to collect seepage from refuse piles with subsequent treatment if necessary.
6. Ponds or ditches to protect against overflow in slurry refuse dams. Slurry refuse disposal requires safety considerations in addition to environmental.

As previously indicated, surface run-off in the immediate area surrounding preparation plant facilities presents another pollution problem requiring careful planning. Run-off from haul roads, refuse disposal piles, and outside raw and clean coal storage areas are a potential source of contamination to nearby surface waters. The elimination of this contamination and the maintenance of environmental quality are responsibilities which must be borne by the coal preparation plant operator. Several current industry practices to control this pollution are:

1. Construction of ditches surrounding preparation facilities to divert surface run-off and collect seepage that does occur.
2. Installation of hard surface over the entire area with proper slopes to direct drainage to a sump. As is the case in the previous technique, collected waters are pumped into the preparation plant for processing.
3. Storage of coal in bins, silos or hoppers with pavement of haul roads and loading points. Run-off is collected in trenches.
4. Establishment of a good vegetative cover of grasses on the surface surrounding preparation facilities to control erosion and sedimentation and to improve aesthetics.

Coal wastes generated by previously uncontrolled surface mining and dumping of preparation plant refuse continue to cause environmental and aesthetic problems. One potential method of treatment developed by the United States Bureau of Mines employs powerplant fly ash as a soil-building amendment. Application of tonnage quantities of fly ash has resulted in successful revegetation of experimental sites totalling 83 acres of orphaned surface mines and 59 acres of refuse material. Costs include regrading, mixing of ash and spoil, seeding, fertilizing and mulching, but are highly dependent upon haulage of fly ash.

Summary

The problems associated with coal waste disposal arise from the origin and character of the coal seam, the mining and processing methods employed, the terrain available for the disposal site, and the construction controls applied. These factors exist in a complex interrelationship. A coal seam with a large percentage of impurities produces a greater quantity of refuse, which, in turn, requires the use of a larger disposal area. Utilization of an open or closed processing system may or may not dictate the construction of a large impoundment for slurry disposal.

Silt, heavy metals, and acid constitute the major water pollution hazards of coal refuse. The data tables list the substantial amounts of aluminum,

magnesium, calcium, manganese and iron that were found in many samples. The sulfur, present in many eastern coals, contributes to the wide range of acidities contained in waters from coal operations. The amount of pollutants can be related to the compaction of the refuse, angle of side slopes, soil cover or surface water control, and the basic geologic formation of the coal.

Remedial action is presently being taken to eliminate or substantially reduce the coal waste disposal problems. Many old sites are being reclaimed by the coal industry as a public service or as a private research endeavor. Federal research programs are investigating the effects of regrading, covering, and sealing refuse to reduce the potential for water pollution. Several state programs are being implemented to clean up abandoned areas and to control active and future operations. The state permit systems are becoming effective in encouraging preplanning and applying engineering design criteria to waste disposal piles and ponds.

The final solution to the problems of refuse disposal, especially in relation to water quality, is still in the future. Short-term improvements are definitely observed. Various research and demonstration projects are making short-term improvements, but what will be the long-term result? Will acid and heavy metal ions continue to leach from a sealed refuse dump, or will they migrate to the surface and render the area devoid of vegetation? Continuing efforts are necessary to refine and evaluate techniques for "hollow fill" disposal, surface sealing, direct planting, and refuse utilization.

RECLAMATION OF TERRAIN EXPLOITED BY LIGNITE OPENPIT MINES

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"POLTEGOR"
Principal Investigator

Introduction

The obligatory regulations in Poland define the efforts one has to make in the process of reclaiming land values, which is the result of industrial activity, including mining lands which have foregone their agricultural and forestland usability. The basis of reclamation activities according to these regulations is composed of the following formulations.

- Lands appropriate for reclamation and economic adaptation are all the terrains which have lost their agricultural or forestland character as a result of industrial activity carried out on them.
- The reclamation and economic adaptation of terrains has to be planned and realized during all phases of industrial activity, and it should be based on reclamation and economic adaptation documentation.
- The reclamation of land consists of a properly illustrated terrain profile, the regulation of hydrologic conditions, the preservation of biologically valuable soil layers, the restoration of soils or their neutralization, or fertilization, the introduction of pioneering character vegetation, slopes consolidation, and the development of a necessary network of access roads.
- Economic adaptation of lands consists of the use of agro-technical treatments, having as their goal an adequate and proper soil formation, performance of a supplementary, water ameliorating work, and also the construction of other supplementary objects and installations and above all production activity.
- The reclamation is to be executed by a company which causes the loss of cultivable land values, either in terms of agriculture or forestlands.
- The economic adaptation is to be accomplished by companies, to whom the reclaimed regions will be assigned for use in the future.
- The reclamation of the despoiled lands has to be conducted in stages, since the regions are becoming redundant to industrial activity disposition, and the reclamation should be completed not later than four years after the industrial activity ceases.
- The economic adaptation is to commence immediately after the reclamation has terminated.

Taking Over and Transforming Terrains Effected by Lignite Openpit Mining

The lands occupied by lignite strip mining are being transformed in various ways. A rudimentary main portion of them is being transformed as a result of direct exploitational work--the displacement of earth masses. On the remaining portion, a change is being made in terms of its current use; erected on these areas are the associated industrial, transport, administrative and dwelling, social and recreational objects and similar arrangements. In the existing strip mines, taken over for these purposes, are about 16 percent of the regions generally assigned for openpit mining. A comparatively high proportion of allocated land for the erection of associated construction is attributed chiefly to the fact that all presently exploited mines are situated in economically rather poor regions. On the areas where associated objects and installations have been localized, no reclamation, as a rule, will be taking place. Permanent arrangements and the objects built will be assigned for their further utilization by their future user, who according to his own activity will make future adaptations connected with the changed specialization. Areas not built upon and only used to store materials, or as assembly places, as safety pillars, provisional roads etc., will be cultivated without any reclamation as required in the context of the terminology explained in the introduction.

The issues of reclamation and economic adaptation apply only in their full scope to terrains directly transformed by the exploitation activity. The transformations are fundamental since they concern alterations in land configuration in the physico-mechanical and chemical composition which is of quantitative and qualitative importance. The scope of such changes is stipulated by the geological formation and by the exploitation technology employed. On all the mining areas after the exploitation, three fundamental forms of terrain are formed (differing first of all in their shape and then in their water conditions):

1. External stacks--eminently uplifted above the adjacent natural surroundings;
2. Internal stacks--formed flush with or sometimes a little above the level of the surrounding land; and
3. Final excavations--terrains depressed in comparison with the adjacent terrains.

The differences in the physico-mechanical and chemical properties of soils occurring in these land forms within the limits of particular mines are insignificant. Between various mines, however, there are fundamental differences.

Regarding the physico-mechanical properties, the open pits are conventionally divided into two groups:

- The pits with an overburden made out of cohesive materials, and
- Pits with sandy overburdens.

To the first group of mines belong the ones from the Konin and Turów regions, and to the second group belongs the now constructed Belchatów mine along with the recently completed "Przyjaźń Narodów" mine. As far as the chemical properties are concerned, to precisely state what things affect the plants soils toxicity, the three following groups of mines are specified here:

- Mines with a neutral or a slightly alkaline overburden;
- Mines with an acid overburden of a pH value from 4.5 to 6.5; and
- Mines with a very acid overburden of a pH below 4.5.

To the first group belong mines from the Konin and Belchatow areas, to the second group Turów, and to the third group the "Przyjaźń Narodów" mine. The basic components of toxicity are the iron sulphides and especially the pyrites, markasite pyrrhotite, and hydro-treolite. An additional source of toxicity is probably the humic combinations contained in the lignite, which in a strongly acid environment are passed into the liquid phase of the ground medium and can manifest their chemical, or biochemical, toxic influence.

Moreover, soils in all mines have a low content of components occurring in a form assimilable by the plants, mainly of phosphorus and potassium.

One anticipates, as far as the surface area is concerned, that the area jointly taken over for the current strip mining of lignite, until the end of its exploitation, will amount 14,100 ha. Adopted for this area was the following structure showing the directions of economic adaption:

Direction of economic adaption	Area ha	Participation % in relation to the total areas
agricultural	4,610	32.4
forestland	7,070	49.6
water reservoirs	1,300	9.1
municipal	360	2.5
other and industrial	900	6.4
Total	14,240	100.0

For purposes other than agricultural cultivation, an area representing 1,260 ha will be handed over in a final settlement; this does not even constitute nine percent of the area assigned for the takeover. This is an insignificant loss which, after considering the advantages connected with the activation of the regions, should not be regarded as losses. In assigning the direction of economic activation, an important factor is the configuration of the exploited areas. Most often external stacks are appropriated for forest reclamation. However, their flat tops may well be thriving on agricultural cultivation and therefore may not be appropriated. A final decision in this matter may usually be taken during the first phase of reclamation and even during the cultivation itself.

The Characterization of Reclamation Work

The reclamation process of exploited areas is divided into three phases: the preparatory, the essential, and the thorough one.

The preparatory phase of reclamation is composed of the following:

- To learn all the factors stipulating correct solutions in the field of reclamation and final land destination;
- Directions assigned for soil destination;
- Project design of the reclamation and recultivation.

This phase begins with a qualitative testing of rocks found in the deposits and ends with a precise scheme of methods and means for a reclamation treatment

plan of the detailed phase. On the basis of a thorough quantitative and qualitative analysis of the overburden rocks and soils on the adjacent terrains, the guiding principles and recommendations in this phase are being defined regarding exploitation and stacking technology; as such, a technology should determine the quality of the material occurring in the soil top layer on the stacks and also the geometrical shape of these stacks. Coordinated in this phase are the determinations of the land destination and the choice of future users of the terrains to be reclaimed. The regional administrative authorities assign the directions of reclamation and the future users. In this phase, also, the mine begins to cooperate with the future users of the reclaimed areas, and this cooperation ranges from a coordination of the planned details of solutions to rendering a service in a realization of specialized operations. For instance, a farming company may execute some part of the work paid for by the mining company.

The phase of substantial reclamation includes the following:

- The shaping of a terrain configuration and regulating the hydrologic conditions in the reclaimed lands and their surroundings.
- The biological utilization of the valuable soil layers.
- The reproduction of soils with technical methods, when necessary neutralization or effective insulation of toxic compounds, or fertilization of barren, sterile formations occur.
- The reconstruction or the construction of necessary access roads.

Thus, reclamation comprises access and the preparation of a surface for specialized cultivation treatments, connected with the introduction of vegetation. This, then, is the phase of earth work performance. The fundamental terrain profile formation is being carried out by the essential big stackers, based on instructions and recommendations of reclamation. So within the framework of reclamation on the flat tops of the stacks, the necessity arises for more accurate leveling of the surface and the formation of counter-slopes (similar to banks), close to the edges of the slopes. Assessment-wise, one assumes that in the performance of such work a requirement arises for a displacement with bulldozers to a distance of some 20 m. of the soil layers to a depth of about 30 cm.

Experience during the last few years shows that this value can be further reduced. The care and precision of the big stacking operators permitted the achievement of a high accuracy of operation performed by this equipment without any lowering of its output (remember this output reaches 6,000 m³/h). On the flat tops, in the course of leveling, there are removed local depressions and cracks which arise as a result of nonuniform subsidence. A very important matter is the formation of a counter-slope by the slopes edge, a kind of embankment inclined to the flat top inside. Such counter-slopes on the top excellently preserve the slopes system from erosion, which the precipitation water runoffs from the top produce. The issue becomes more important, the higher the slopes are and the more impermeable the soils forming the stacks are.

Primarily, the formation of flat, horizontally leveled tops is to be avoided owing to the difficulty of draining it off, and such waterlogging of the surface slows down the cultivation treatments coming into operation after each of the rainy seasons, especially after thaws and precipitation in the spring.

For these reasons, local downgrades in selected directions are being formed, and ditches are dug to drain the water from the sinkings in the

ground to the offtakes on the slopes. The dewatering ditches are not fortified; a correction is often made of their bottoms' declines by very simple concrete ground braces. Bringing the waters down the slopes is frequently made from prefabricated concrete element, reinforced constructionally only because of their transport requirements and frost effects.

Most attention and efforts require the slopes formation on the external stacks, as these are most exposed to erosion, caused mainly by precipitational water run-offs, with the most unfortunate effect of covering the adjacent regions with a washed-out material from the stack. A liquidation of erosion is therefore an important issue, both as regards the stack reclamation and the preservation of adjacent agricultural terrains. Past attempts at eliminating erosion on the steep slopes by means of the introduction of biological consolidation of trees and bushes or a grassy vegetation on these slopes gave negative results, only diminishing the intensity of the phenomenon. Adequate results were acquired only after an inclination reduction in the slopes. The following system of slope formation is used now:

- An inclination of the whole system of slopes--the stacks are up to 200 m high, conformable to the geotechnical calculations.
- The inclination of the particular slopes not greater than the ratio 1:3.
- A partitioning of slopes higher than 10 m with shelves with a 5 to 7 width, falling toward the slope situated above the shelf. The vertical spacing between the shelves is 8 to 10 m.

On the slopes fashioned in this way, soon after the completion of the earth work, a biological consolidation commences.

A few years ago technical and economic possibilities were considered in detail, and requirements for selective topsoil (0.3 to 0.5 m) collecting and covering for the exploited terrains were developed, thus achieving faster reclamation and recultivation. Completed analysis has proven that such an application is totally unprofitable, chiefly in view of the low land quality on the exploited areas; but the overburden formation in its first near surface worked level (about 20 m) allows, in a controlled way, the stacking on the stack, to acquire soil mixtures with similarly advantageous physico-mechanical properties, which have little or no toxicity. As a result of this analysis, detailed, guiding principles were laid down for mining extraction in all pits, regarding the manner in which to carry out the digging, the transportation, and the overburden stacking. The modernization work is to effect changes in the existing transportation systems to fulfill the conditions of working and stacking the overburdens in a controlled way.

The phase of thorough reclamation comprises:

- Further particular regulation of hydrological conditions on the reclaimed regions.
- A neutralization of toxic formations and fertilization of sterile soils, and, in a case of necessity, improving their physico-mechanical and chemical properties.
- Introduction of a means of reproducing the biological conditions and halting erosion vegetation.
- A biological, or a biological-technical, consolidation of slopes and belts of land at their base and on their top.
- In the case of exploited pits, for water management, the erection of necessary objects and hydrotechnical installations having as their goal the preservation of water from vanishing or pollution and for water storing.

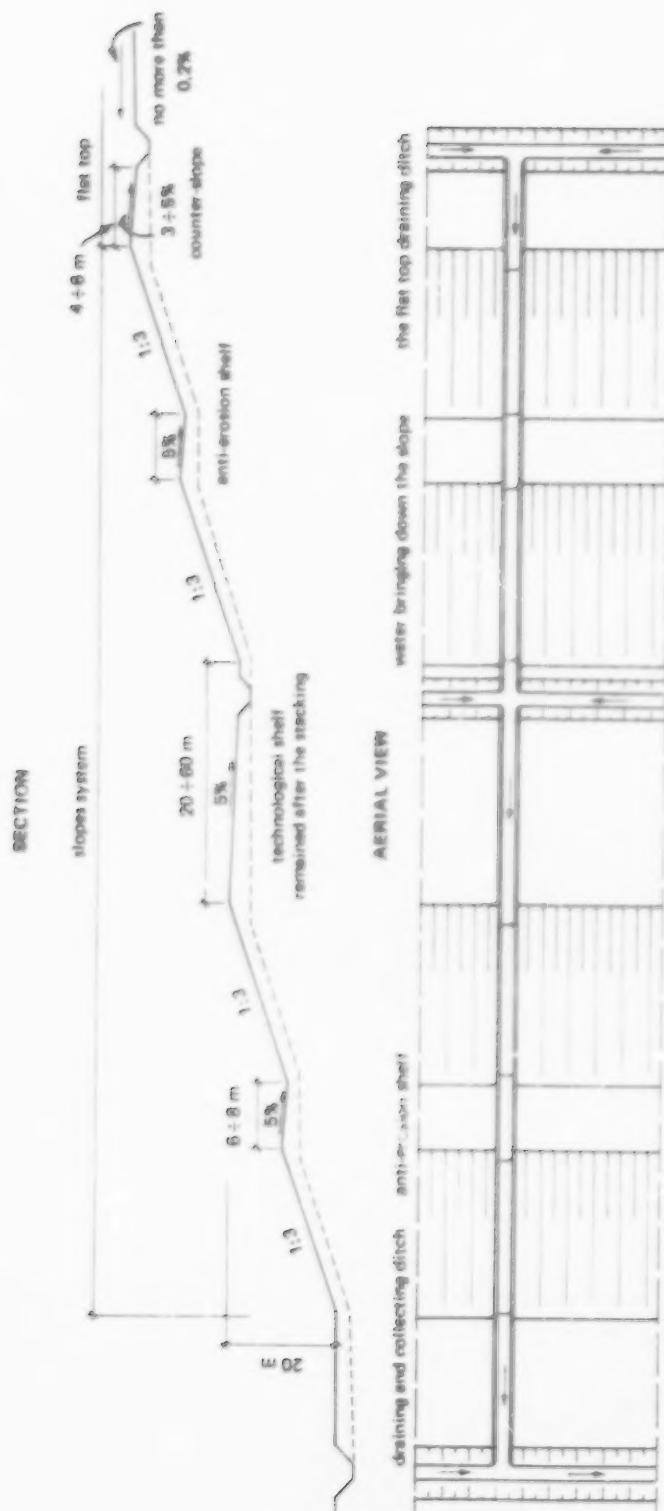


Figure 1. Scheme of the External Stack Slopes System

In a framework of further regulation of hydrological conditions, additional ditches will be dug to drain off the consequent further subsidences which cause local sinkings in the ground and the eventual additional water off-takes made on the slopes. A correction of counter-slopes, erected previously on the flat top edges, and also a maintenance of the collecting water ditches will be carried out. Before coming to the neutralization and fertilization treatments, shortened analyses are being made of the soil material in order to establish proper doses of neutralizers and fertilizers.

Most often used in neutralization are ground agricultural quicklime (CaO) or ground phosphate rock (30 percent P_2O_5 , and 25-50 percent CaO --chiefly in a form of an apatite and calcite). Rarely used is ammonia water due to the big losses in neutralizer, caused by the fact that the forthcoming salts easily undergo a decomposition. An advantageous characteristic of employed neutralization by means of ammonia water, however, is the speed of reaction, which enables an earlier introduction of vegetation. In the mine "Przyjaźń Narodów" which is characterized by strong acidity of sandy soils (about $\text{pH} = 3$), there has been carried out with the cooperation of the E.P.A., research to neutralize the magnesium oxide lime, which is a waste product derived from zinc production. Such a lime contains significant amounts of CaO and MgO , and also a number of trace elements. This lime, in past investigations, gave very good results. In the area of industrial wastes, fly ash coming from the lignite fired power plants is also used in neutralization. In these cases, ashes are being mixed with the overburden in a continuous process and regulated on the transporting overburden conveyor belt and jointly stacked. An additional advantage acquired with such a solution is the liquidation of burdensome ash stacks. Depending on the level of toxicity, the neutralizers are applied in a single or double layered manner both before and after the ploughing. Combinations of various neutralizers are also being used.

In investigations carried out in Turów, for example, where the $\text{pH} = 5.5-6$, in the cooperation with E.P.A., the following neutralizer combinations are used:

- CaO in a dose five T/ha, single layer
- CaO in a dose ten T/ha, double layer
- CaO in a dose five T/ha and the ground phosphate rock in a dose three T/ha in a double layer; the bottom layer--ground phosphate rock; the top layer-- CaO
- The ground phosphate rock in a dose three T/ha, single layer
- The ground phosphate rock in a dose three T/ha, and 25 percent ammonia water in a dose five m^3 /ha, single layer

As nourishing components to enrich the soils, the following fertilizers are used most often:

- N - urea, ammonium nitrate
- P - basic superslag
- K - potash salt.

The basic doses applied to the soils, before the sowing out of plants, are in quantities that depend on the kind of soils--from 200-600 kg/ha.

Sown onto the growing vegetation is nitric fertilizer in the form of an ammonium nitrate, in quantities up to 100 kg/ha.

The introduced pioneering vegetation used for reclamation is selected according to the terrain configuration, soil graining, chemical properties, climatic conditions, exposure, and other requirements.

The rule is to introduce grass mixtures and papilionaceous plants on the flat tops, and on the slopes trees and bushes under a cover of grass and papilionaceous plants. The compositions of the employed mixtures are variegated in regard to both the number of species and the percentage of particular kinds present in the mixture.

Examples of the compositions of mixtures of grass and papilionaceous plants and species of trees and bushes used in the research conducted in cooperation with the E.P.A. are shown in the following tables.

Compositions of Mixtures of Grasses with the
Papilionaceous Plants

Ord. nr	Kinds of plants	Proportions by weights of seeds in the mixture in kg/ha				
		Mine Turów		Mine Przyjaźń Narodów		
		Tops	Slopes	Mixture nr 1	Mixture nr 2	Mixture nr 3
1	2	3	4	5	6	7
1.	<i>Agrostis alba</i>			8		
2.	<i>Axrhcnatherum elatus</i>		4	6		
3.	<i>Bromus inermis</i>				8	
4.	<i>Festuca pratensis</i>			6		
5.	<i>Festuca rubra</i>	3	4			6
6.	<i>Lotus corniculatus</i>	8	10		20	
7.	<i>Lolium sp</i>				6	
8.	<i>Lolium multiflorum</i>					6
9.	<i>Lolium perenne</i>	3				
10.	<i>Lupinus polyphyllus</i>	25	30	30		
11.	<i>Melilotus albus</i>		5			5
12.	<i>Phleum pratense</i>	3	4			8
13.	<i>Poa pratensis</i>				6	
14.	<i>Trifolium repens</i>	3	3			10
	Together	45	60	50	40	35

Species of trees and bushes, cuttings and shoots planted in the spring of 1974 on the external stacks slope are presented below. EXPERIMENTAL PLOTS KWB Turów - 1974

- 1) *Alnus glutinosa*
- 2) *Robinia pseudoacacia*
- 3) *Elaeagnus angustifolia*
- 4) *Caragana arborescens*
- 5) *Larix decidua*
- 6) *Quercus borealis*, Q - robur
- 7) *Populus Robusta*

- 8) Populus Hybrida - 275, Populus Hybrida - 194
- 9) Sorbus aucuparia
- 10) Rhus typhina
- 11) Padus serotina
- 12) Fraxinus excelsior
- 13) Acer platanoides
- 14) Acer pseudoplatanus
- 15) Sambucus nigra
- 16) Carpinus betulus
- 17) Fagus silvatica
- 18) Salix sp.
- 19) Populus sp.

Remark: Planting effected at intervals of one x one m or 1.5 x 1.5 m.

Parallel with full scale reclamation, research goes on regarding the reclamation and economic adaptation laws. Much of it is characterized as composite research executed on a technical scale, such as the aforementioned cooperation with the E.P.A. concerning the reclamation of toxic stacks, and also research into the agricultural utilization of soils with a limited scope of reclamation phase work, conducted in Konin. Such investigations and the investigations of selected problems are being performed in all countries in order to protect the environment, and they will eventually assure continued progress in reducing the periodical negative influence which openpit mining is having on agriculture and forestry.

SEDIMENT CONTROL AND SURFACE MINING

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Introduction

The construction of a road to facilitate mining and prospecting is the beginning of the damage to the ecosystem by surface mining. The vegetation and topsoil rich in organisms are pushed aside or covered with subsoil and rock. All too often in hilly terrain the "cut and fills" are not balanced, and "cut" material is pushed over the hillside. More "fill" material must be borrowed thus expanding the amount of disturbance. Run-off from adjacent land, road surfaces and berms, if not properly controlled, causes accelerated erosion, producing the first off-site damage. Prospecting is often performed with dozers by ripping the soil surface to reveal outcrops of minerals or fuels. These scars are additional sources of sediment. In some states, the control of sediment from the actual mining operations is required, but haul-roads and prospectings which are not controlled may yet contribute as much sediment as the mine itself.

Next in the mining sequence is the clearing and grubbing of trees, brush, etc., from the mine site. In some situations the trees are harvested. At other times, the material is windrowed below the mine disturbance to serve as a filter for sediment. These large areas of bare soil are exposed and subject to accelerated erosion.

A massive earth moving operation then begins. Some states require that the topsoil and/or subsoil be stockpiled for later spreading during final grading. The overburden rock is usually fractured by blasting before being ripped apart and moved by shovels, draglines, dozers, front-end loaders or scrapers. The mining process loosens the overburden material making it more susceptible to erosion.

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After exposing the ore body or fuel, appropriate equipment is used to remove it for market. Low grade mineralized waste material is often associated with the seam being mined. This material can be a major source of chemical

pollution and should be specially handled. Following removal of the commodity, the backfilling of the excavation begins. Similar environmental degrading accompanying overburden removal can occur. The final process, termed reclamation, involves grading, replacing the topsoil, where practical, and revegetation. The practices used during reclamation have a major bearing on the recovery rate of the surface mine.

Erosion and Sediment

Sediment in water reduces light penetration and alters the temperature which directly affects aquatic flora and fauna. Fish production is hindered because food organisms are smothered, spawning grounds destroyed and pools filled. Sediment places an additional burden on treatment plants and cost as well as on aesthetic and economic values (McKee and Wolf, 1963). Sediment deposit in navigable streams must be removed at a high cost. Streams choked with sediment have reduced carrying capacity and are subject to flooding.

The mechanisms of soil erosion by water consist of soil detachment by raindrop and water scoring and transported by surface flow. Sediment yield can best be described by the Universal Soil Loss Equation (USLE) which combines the principal factors that influence surface soil erosion by water (Roth, Nelson & Romkens, 1974). The equation takes the form:

$$A = RKLSCP$$

where: A is the soil loss in tons/acre
R is the rainfall factor
K is the soil erodibility factor
L is the length of slope factor
S is the steepness of slope factor
C is the cropping and management factor
P is the erosion control practice factor

The U. S. Department of Agriculture has prepared a handbook for utilizing this equation (Wischmeier and Smith, 1965).

The rainfall factor R reflects the potential of raindrop impact and runoff turbulence to dislodge and transport soil particles. This factor is dependent upon the rainfall pattern and intensity of a specific locality. The mine operator has no control over this factor.

The soil erodibility factor K reflects the most significant soil characteristics affecting soil erodibility. For surface soils, the soil texture, organic matter content, soil structure and permeability are the key parameters. Recently Roth et al. (1974) have shown for subsoils low in organic matter and high in clay that the chemical properties of the material such as its iron and aluminum content have a major bearing on its erodibility. The K factors for the bedrock material fractured during mining and later weathered remains to be defined. The mining company has limited control of their material during the mining operation but can take advantage of the soil erodibility during reclamation by making every effort to place that material with the lowest erodibility factor on the surface. This material should have a high organic matter content, high permeability and be granular. In many situations, the practice of top soiling is a step toward obtaining a lower K factor if the soil is properly handled and placed.

The length of slope factor L reflects increased sediment detachment and transport as runoff velocities and volume increase with increased slope length. Spoil should be stored and final graded to prevent long slopes. Where long slopes must be left, control structures should be installed to break up the slope (see P factor).

The degree of slope factor S also recognizes that runoff velocity increases as the slope of the land increases. For example, increasing the steepness of a slope from 10% to 40% doubles the flow velocity. Steep slopes should be discouraged in mining operations. Slopes of less than 33% are recommended but are sometimes difficult to obtain in mountain type surface mining where the original slope equals or exceeds 33%.

The cover management factor C reflects the influence of the type of vegetative cover, seeding method, soil tillage, disposition of residues and general management level. The C value ranges from near zero for excellent sod to 1.0 for bare soil. Mining firms can take advantage of this factor by establishing quick cover of grasses and legumes and using proper tillage techniques. The C values decrease as the percent ground cover and the percent canopy cover increases and the height of the canopy decreases. The application of mulches such as straw, woodchips and chemicals, also decreases the C factor.

The practice factor P accounts for erosion control structures such as terraces and diversions. These practices are used to influence the drainage patterns, runoff concentration and runoff velocity. Numerous such practices are available and the mining company should take advantage of those applicable to their situation.

A study by Collier et al. (1964) showed the average annual sediment production from a surface mined watershed was 42 tons/acre, more than 1,000 times higher than an unmined watershed. Curtis (1974) studied three watersheds in Kentucky and found the sediment yield to range between 0.84 and 1.27 area-inches of area disturbed. He could find little correlation between sediment yield and the amount of land disturbed and concluded that methods of mining and handling the overburden are major factors controlling sediment yield. He also noted that the highest sediment yields were measured during the first six-month period after mining. This indicates the need for more attention to activities during and immediately following mining and the importance of an adequate cover of vegetation and of establishing control structures as quickly as possible after mining ceases.

Environmental Control of Surface Mining

EPA (Grim and Hill, 1974) has prepared a comprehensive report on "Environmental Protection in Surface Mining of Coal," which describes methods of pre-planning, mining and reclaiming surface mines.

In summary, environmental control starts in the mine planning stage. Data collected at the proposed mine site on the topography, overburden characteristics, ground and surface water and climatic conditions are used to plan the mining technique to ensure (1) that proper erosion control is established, and (2) that selected overburden handling is accomplished to prevent acid mine drainage and ensure revegetation. Major irreversible problems have resulted when environmental concerns have not been considered along with extraction procedures. Good premining data collection and mine planning are the key to final recovery of the disturbed area.

Major advances in surface mining methods have been realized in the last few years. The collection of topsoil and subsoil for later spreading over the reclaimed spoil has been a major step in accelerating the recovery of stripped areas. Selective handling of the toxic overburden and its proper burial have reduced both acid and erosion problems. For mined areas on rolling to flat land, the grading of the land to a topography similar to that before mining has not only resulted in land, more pleasing to the eye, but has made the land more useable and reduced the erosion threat because it is easier to revegetate. In the mountain areas, the advent of mining methods with the colorful names of "head-of-hollow fill," "over the shoulder," "put and take," "block out," and "mountain top removal," have led to ways of reducing the silt and landslides associated with steep slope mining. Erosion control practices are being adopted but far more could be done in this area. Many states are now requiring sedimentation ponds below mining operations. They are a major step forward in reducing the off-site sediment load; however, design modifications will be needed to make these ponds more effective.

Reclamation and revegetation "know-how" have increased significantly. The days of the pine tree on six-foot centers are gone. Careful consideration of the nutrient deficiency of the spoil and needs of vegetation are being taken into consideration. Lime, fertilizers, and mulches are being used. Better balanced mixtures of grasses and legumes are being planted. All weather seeding, instead of only twice a year, is reducing erosion that occurred while awaiting the planting season. Nurse crops to hold the soil and assist permanent species are being utilized. Hydroseeding is more common in difficult areas. Good seed bed preparation is ensuring better and faster establishment of vegetation. These practices lead to establishing a permanent vegetative cover more quickly, which is the first step toward recovery.

Smith, et al., (1974) have recommended that spoil be considered as a young soil and treated accordingly. They recommend that spoil be classified under the U. S. Department of Agriculture soil classification system as Spolents under the order level of Entisols, which are defined as recent soils that have little or no evidence of development of pedogenic horizons. An intent here would be to bring to bear the knowledge of soils on the development of manageable soil units. Some investigations have studied the development of soil from spoil. Smith, Tryon, and Tyner (1971) studied 70 to 130-year old spoils and reported that natural soil proved superior to old spoils in bulk densities, porosity, infiltration, nitrogen, and organic matter whereas the old spoils were superior in depth of plant rooting, total available water holding capacity, and certain plant nutrients. Others (Krause, 1964) have reported increased nutrient levels in spoils because nutrients had been leached and utilized by plants from the original soil, while certain strata in the overburden contained large quantities of potassium and other nutrients. Selective placement of the overburden material is critical to recovery. Acid, toxic and physically poor material must not be placed near the surface. Material that is capable of supporting plant growth is required. The growth-supporting material may require additions of soil amendments such as lime and fertilizer. The most recent trend has been the removing of "topsoil" and then its replacement after grading. "Topsoil" here may be defined as the horizons of natural soil that are capable of supporting plant growth. Several state laws now require top soiling and the pending Federal Surface Mining Control and Reclamation Act will require it for coal mining throughout the United States. Although top and subsoil may not always be ideal, it usually has certain advantages over other materials, including higher organic matter, better moisture-holding capacity, natural seed

source, and soil microorganisms. Soil microorganisms are a key to the development of soil material and fresh bed rock-type materials have insufficient organisms.

Recovery will be much faster and less fragile in the humid eastern United States as compared to the arid and semi-arid Western states. The low rainfall and saline soils of the West place additional stress on recovery. The available plant species that will grow on these areas are limited, slow growing, and often are hard to establish. A popular belief in these states is that the acceptable cover should be native vegetation; however, the know-how on culturing native vegetation is limited, seed sources are scarce, and germination may be as low as 10%.

There are striking examples of surface-mined areas that have recovered to productive use as forests land, high yield cultivated land, pasture, recreational parks and even home and industrial sites. On the other hand, there are even more examples of land that are still drastically disturbed. The key to recovery has been the attitude and reclamation techniques of the mine operator and the physical and climatic conditions at the mining site.

Sediment Ponds

Ponds have become the primary sediment control method for most surface mines. Several states require their use either by law or regulations. Although frequently used, more often than not they are improperly designed for maximum suspended solids removal, poorly constructed, receive limited maintenance and are inadequately "closed down" or abandoned. Most ponds, when they are designed, are designed not for maximum suspended solids removal, but based on "rule-of-thumb" suspended solids storage capacity (0.125 to 0.2 feet acre-ft per acre of disturbed area), proper dam design for safety, and proper location and capacity of overflow and emergency spillway. All of these factors are important, but may not lead to efficient sediment removal. An evaluation by EPA of ponds constructed and in use revealed little correlation between the design submitted with the surface mine permit application and the structure constructed. In many cases the actual pond was a function of the topography of the site, the earth moving equipment available, and the experience of the operator, and not the design. Ponds are often built in locations remote from the operation and in nearly inaccessible locations. Thus, they received little regular attention and maintenance, which leads to reduced efficiency. Often inadequate measures are taken when a pond is abandoned upon completion of mining. Left unattended, dams deteriorate and finally fail discharging the collected sediment, sometimes as one large mass.

Design considerations. Some factors that need to be considered in pond design are:

1. Advantages and disadvantages of a single large pond versus two or more smaller ponds.
2. Location of pond.
3. Size and depth of pond for maximum sediment removal and storage.
4. Shape of pond.
5. Inlet design.
6. Outlet design.
7. Close down.

Number of ponds. Some mines, particularly in mountainous areas, use several small ponds. These may be in series or several small ponds may discharge

to one large pond. To date the primary reason that more than one pond is used is because the topography of the land is unsuited to one single large pond. Several ponds have advantages over one large pond: (1) Passing the water from one pond to another may improve retention time and suspended solids removal; (2) if cleaning is required, smaller ponds can be more easily handled with common equipment; (3) smaller ponds can be easily removed at the end of mining; and (4) "turn overs" and wind erosion of banks are less.

One large pond is usually better designed and constructed than smaller ponds which are often dug out with a dozer. They can be designed for the life of the mine and never require cleaning. Cost of several ponds as compared to one pond will depend on the individual situation. Several ponds may require more earth moving work; whereas, one pond may require more expensive dam construction, outlet and emergency spillways.

Location of pond. Some agencies recommend that the pond be built in the main drainway because construction sites are more available and all the surface runoff from the mine area passes through the pond. Others recommend that they be placed out of the main draining to reduce unnecessary flow from being treated, and to facilitate the removal and abandonment of the pond. Location of the pond will be dictated to a large extent by the topography of the mine area. It is important that access to the pond be available for regular inspection and maintenance.

Size and depth. Size and depth of a pond should be based on providing the necessary retention time, with short-circuiting taken into consideration, for maximum suspended solids removal. In addition, sufficient solids storage must be provided for the life of the ponds or for a specified cleaning interval. Retention time should be calculated for when the pond has reached its full solids storage capacity, not when it is empty, in order to have high performance throughout pond life. Very large and deep ponds are often subject to wave action and turnovers. These factors should be taken into consideration.

Shape of pond. The shape of a pond has a major bearing on short-circuiting of flow and thus on retention time. Tear drop and tooth-shaped ponds usually have less short-circuiting than elongated ponds perpendicular to the inlet. The shape of the pond should facilitate suspended solids storage, long retention times and minimize short-circuiting.

Inlet design. Inlet design is very important to minimize short-circuiting. In many ponds the water enters at one point under high velocities. The high velocities are not conducive to good settling and often stir up solids already settled. The inlet should consider multiple inlets, baffles, etc. to spread the flow, and reduce inlet velocities.

Outlet design. Outlet design is also critical for good pond performance. One discharge point leads to poor performance because of short circuiting. Trough-type outlets instead of stand pipes and horizontal pipes through the dam should be considered. The stand point full of holes is a questionable practice, since sediment often is carried away from the pond bottom by scour with the first flow.

Close down. During the design phase, the method for removing or stabilizing the pond upon completion of mining should be considered. If the pond is to remain, then the responsibility for its maintenance should be established.

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RECLAMATION OF COAL-FIRED POWER PLANT ASH PL. 2

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Introduction

In the next 15 years, production of coal-fired power plant wastes will grow in the following way (Figure 1):

1975	-	11.9 mil.	(metric tons)
1980	-	17.5	"
1985	-	24.4	"
1990	-	29.9	"



Figure 1. Actual and Forecasted Rates of Coal-Fired Power Plant Wastes in the Years 1970-1990.

With an average height of stacks coming to 20 m, this means that in piling up wastes alone one would have to cover an area (taking the weight by volume 0.9 Mg/m^3 and adding to it 20 percent for creating protective belts and slopes) as follows:

1975	-	7.93 km^2
1980	-	11.66 km^2
1985	-	16.25 km^2
1990	-	19.90 km^2

In the years 1975-1990, the ash piles will occupy an area of 210 km^2 , i.e., 0.07 percent of the country area. This estimate was made based on the assumption that there will be no fundamental change in the rate of utilization of ash as a secondary raw material.

One can infer from the presented figures about the importance of the problem of utilizing these wastes and above all about their piling up in accordance with regulations and also with the possible economic exploitation of the stack areas.

Regulations

The Act of 26 October 1971, regarding the protection of agricultural and forestry land and the reclamation of soils, obligates the Power Engineering Utilities to reclaim--within four years of their ceased operation--the devastated regions, and to hand over these regions to the proper authorities for their use in the interests of the national economy.

The executive decisions determine the manner in which land is to be reclaimed and the procedures for accepting reclaimed regions. The law prohibits the take over of agricultural or forest lands for purposes other than agriculture. This means a prohibition against erecting stacks of wastes on agricultural or forestry land.

The Decree of 21 April 1966, regarding atmospheric air protection against pollution, divides the country into two zones of protected areas for which permitted concentrations of substances occurring in the air in mg/m^3 were established as follows:

Table 1.

Q. N.	Designation of the substance	Specially Protected Zone		Protected Zone	
		Maximal Substance		Concentration	
		Average Daily	Single Continu- ous for 20 min.	Average Daily	Single
1.	SO_2	0.075	0.25	0.35	0.9
2.	H_2SO_4	0.05	0.15	0.1	0.3
3.	Nitric oxide in terms of N_2O_5	0.05	0.15	0.2	0.6

Table 1. Cont.

O. N.	Designation of the substance	Specially Protected Zone		Protected Zone	
		Maximal	Substance	Concentration	
		Average Daily	Single Continu- ous for 20 min.	Average Daily	Single
4.	Hydrogen sulphide, H ₂ S	0.008	0.008	0.02	0.06
5.	Carbon oxide, Co	0.5	3.0	-	-
6.	Gasoline	0.75	2.5	-	-
7.	Nontoxic dust below	0.075	0.2	0.2	0.6
8.	CS ₂	-	-	0.15	0.045

An allowed quantity of dust fallout cannot exceed the 250 Mg/km²/year for the protected zone and 40 Mg/km²/year for the specially protected zone.

These Regulations Are Being Applied to the Transportation and Stacking Up of Wastes

The decree of 24 October 1974--the Water Act--imposes an obligation on the company to seek and acquire legal permission, whereby water interests must be safeguarded, for the following:

- a. Depositing of wastes on coastal lands, in regions of mined areas, of curative waters, and areas of protected springs.
- b. Bringing the sewage to waters or to the earth. Enterprises seweraging to surface waters or to the ground are obliged to construct and to maintain installations safeguarding waters against pollution. In referring to the stacking of coal-fired power plant wastes, this implies a necessity for building arrangements protecting surface and ground water from contamination with the toxic substances contained in wastes. Standards of concentration in the effluents considered as not detrimental are:

- Dissolved substances - up to 500 mg/l
- General suspended matter - to 20 mg/l
- Chlorides - to 250 mg/l Cl
- Sulphates - to 150 mg/l SO₄
- Ammonium salts - to 1 mg/l N
- Nitrates - to 1.5 mg/l N
- Total iron - to 1 mg/l Fe
- Manganese - to 0.1 mg/l Mn
- Phosphates - to 0.2 mg/l PO₄
- Thiocyanogens - to 0.02 mg/l CNS

- Phenols - to 0.005 mg/l
- Lead - to 0.1 mg/l Pb
- Copper - to 0.01 mg/l Cu
- Zinc - to 0.01 mg/l Zn
- Sum of heavy metals - to 1.0 mg/l
- Boron - to 1 mg/l B
- Sulphides - undetected
- After 24 hours the fluxes should not cause fish to fall asleep
- Reaction - within the limits 6.5 to 8.0
- Total hardness - to 7.0 mval/l

Storage

Pneumatic ash removal is not widespread in Poland. A diagram of hydraulic ash removal and wastes dumping is shown in Figure 2.

Sedimentation basins--wet ash pilings--is an area surrounded by earth dikes, or sinking terrain, to which pulp is conveyed (a mixture of ash and slag with water) under pressure, or by gravity to settle down ash and slag, and make the draining away of supernatant water possible.

As a rule such stackings are divided into three quarters, and this arrangement facilitates exploitation, alternating with the drying and raising the levels of quarters. The discharge of pulp is made in fixed places or in a system of basin wall discharges.

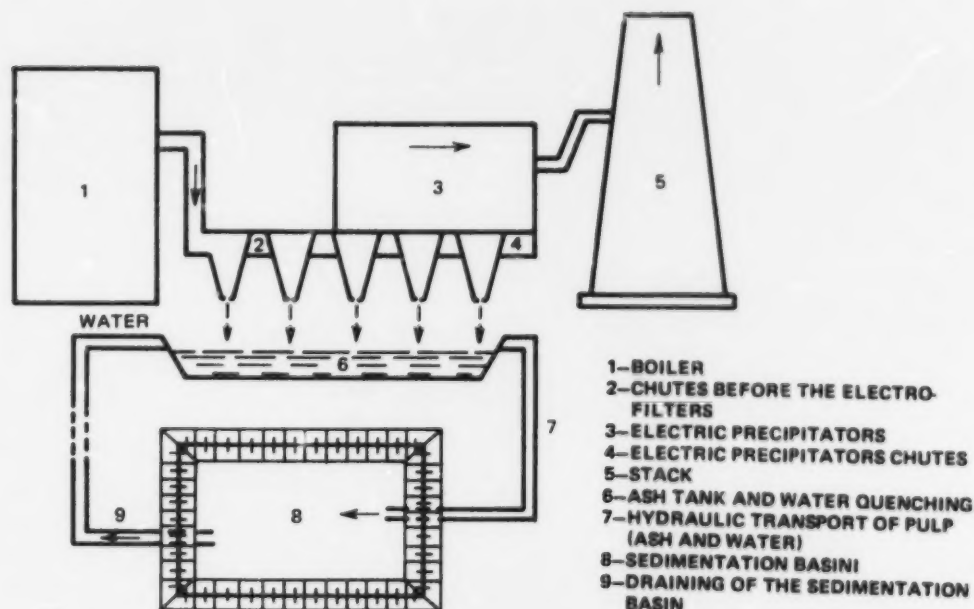


Figure 2. Diagram of Ash Disposal in a Power Plant.

The usual dikes of sedimentation basins are made of mineral soils. After filling in the basins with sedimentation, drying off and raising the dikes' levels with the sedimented material follows (Figure 3). This rise in the level is necessary due to the lack of terrains necessary for piling up wastes. In some enterprises, the dry ash is removed to dry dumps situated at some distance. Transport of ash is then carried by belt conveyors.

The Characteristics of Wastes

Depending on their origin, we divide the wastes derived from coal-fired power plants into two main groups (Figure 4):

- 1) Derived from hard coal, and
- 2) Derived from lignite.

Both groups can be further divided into slags and into ashes according to the composition of their granulation. The slags are formed in the combustion chamber of a boiler during the combustion of coal dust, through an agglomeration of fly ash particles.

Dry ashes are the sintered particles captured during a dynamic flow of furnace gases through such dust-extracting devices as cyclones, decompression chambers, and above all electrofilters.

These two main groups of wastes usually get mixed together during transport to a stack.

Chemically, ashes derived from hard coal are primarily composed of silica (about 40 percent), aluminium oxides (20 percent), iron oxides (several percents), and oxides of magnesium, calcium, sodium, and potassium. The amount of unburned coal usually amounts to a few to several percents. Mineralogically, the ashes consist chiefly of quartz, amorphous coal, and mullite ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$).

Calcium sulphate ashes of burnt lignite (originating from Pliocene deposits in the Konin region) differ materially from aluminosilicate ashes (from Pliocene deposits in the Turoszów region) in their chemical composition and in physico-chemical properties.

Thus, ashes from Konin contain 3.0 to 7.1 percent of Al_2O_3 , and ashes from Turoszów contain around 37 percent of Al_2O_3 . Ashes from Konin have 5.0 percent to 45.6 percent of CaO , but in Turoszów they have at the most 7 percent (usually 1.4 percent). The content of SO_3 amounts to 0.5-9.7 percent in ashes from Konin, and about 0.3 percent in Turoszów ashes.

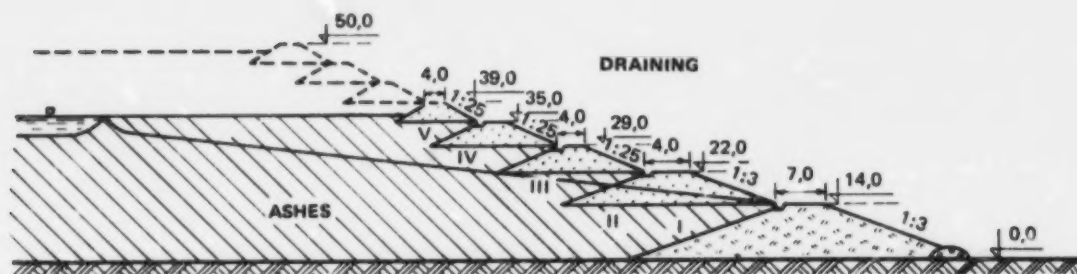
Mineralogically, Konin ashes consist of quartz grains and minerals of the montmorillonite-illite group, but Turoszów ashes constitute quartz and caolinite group minerals.

The granulometric composition of ashes is shown in Figure 5. One has to take notice of the fact that, depending on the manner of stacking, the granulometric composition can differ on the same stack.

Namely, in hydraulic transportation, a segregation of chippings follows after the pulp leaves the pipeline and also during the settling (Figure 6). In the zone near to the pipeline outlet, the chippings are bigger in size (in the share of slag in them) but the division into zones is not clear.

The usefulness of ashes for biological reclamation of particular groups of ashes varies depending on the kind of burnt coal, on the firing technology, on the manner of ash removal, and on the age of deposited material.

The ashes of hard coal are characterized by a strong alkaline reaction (pH 9-11), which neutralizes with time (to pH 8-9), and by minimal resources



- 1 - DEPRESSION CURVE IN CASE OF EMBANKMENT, OF NOT PERMEABLE SOILS.
 I - EMBANKMENT OF SANDY CLAY, II-V - EMBANKMENT OF ASHES AND SLAGS MADE WITH SILTING METHOD

Figure 3. Embankment Superstructure of Ash Sedimentation Basins.

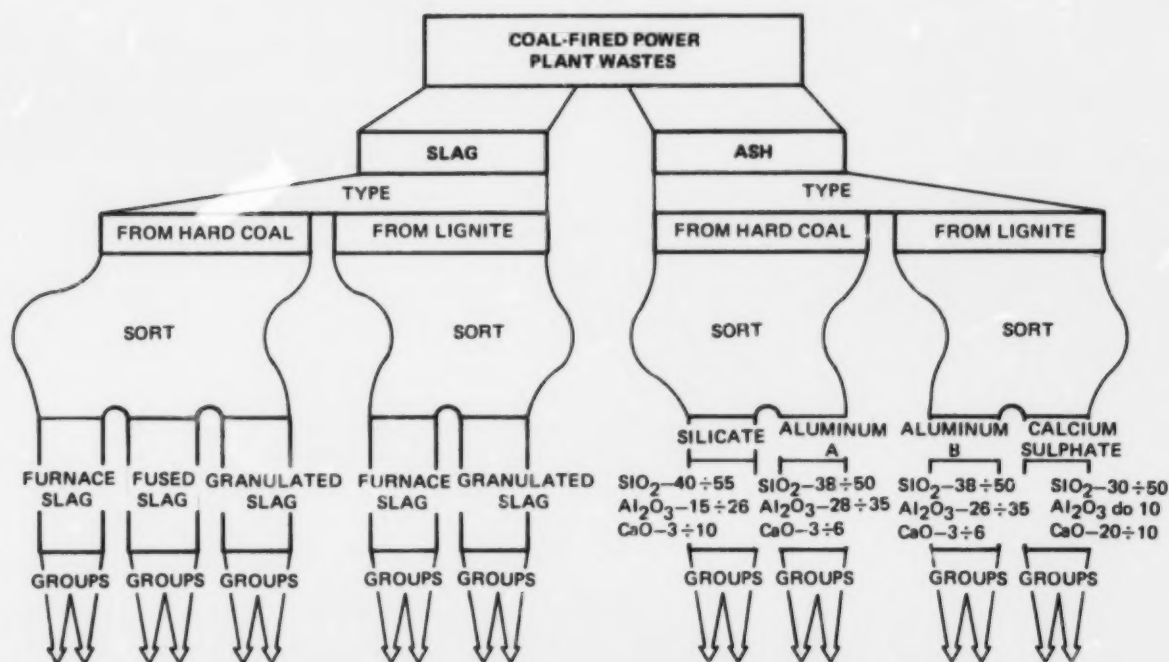


Figure 4. Diagram of Coal - Fired Power Plant Wastes Classification.

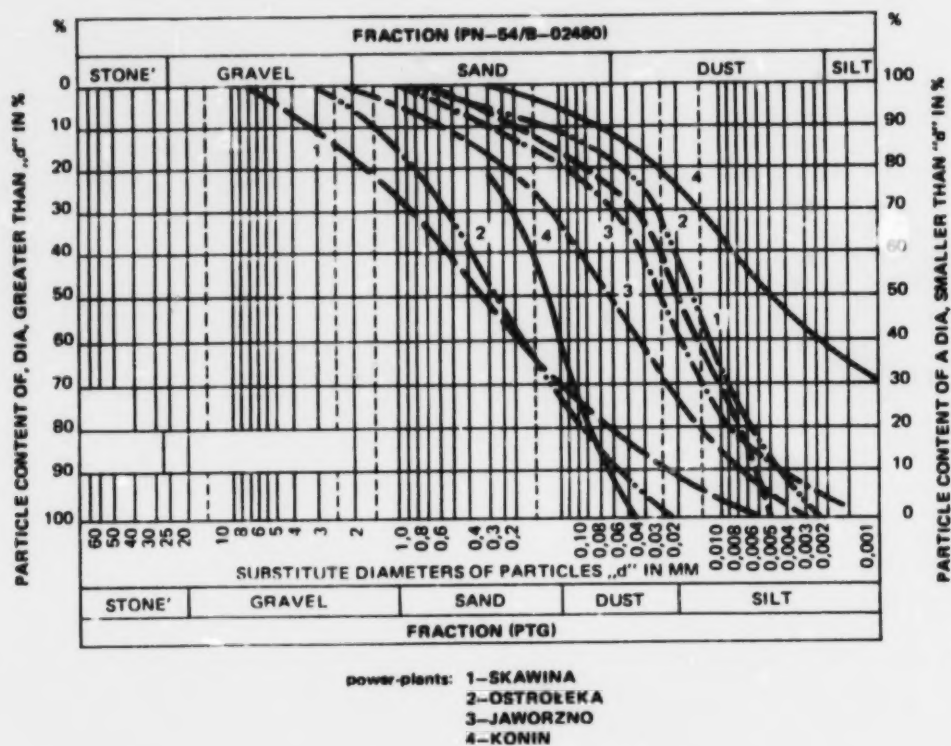


Figure 5. The Curves of Ash Graining.

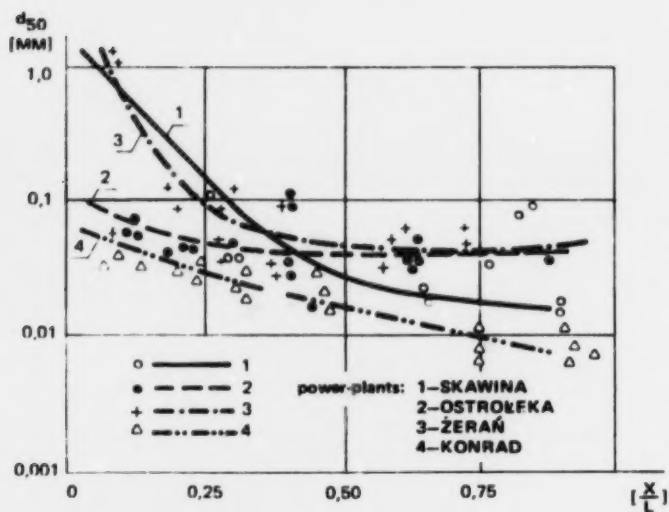


Figure 6. Dependence of the Grains d - Size on a Distance of a Pulp Inlet.

of basic nourishing constituents (N and P_2O_5). The content of forms assimilating K_2O is generally high. Water extracted after 24 hours and after 120 hours indicated that the salinity exceeded permitted rates, and was too high for it to be used in agriculture or forestry.

A significant amount of sodium, potassium semioxides, chlorides, sulphates, and iron compounds was ascertained. The reaction of this water was strongly basic (pH 8.5 to 10.8). Flower pot experiments indicate an unsatisfactory development of the tested plant, as evidenced by delayed and sparse sprouting, slower growth, and smaller crop yields than in washed out sands. This undoubtedly proves the toxic character of the medium. With respect to the granulometric composition, the wastes also have bad characteristics of aeration and water retention (low water-holding capacity and no soil capillarity). Ashes dry up easily, and particles are shifted by the wind, becoming particularly troublesome to the surroundings. The ashes from Turoszow are characterized by a neutral or a weakly acid reaction (pH 5.6 to 6.6). The content of assimilable forms of N, P_2O_5 is very low, and K_2O is insufficient. The porosity of the material is high, and the capacity for storing water, that would be accessible to plants, is minimal. Vegetative experiments indicate a weak sprouting, and probably an unsatisfactory development of the tested plants. If a plant is well adapted to difficult conditions (as oats or some sorts of grass), then a reasonably good crop can be produced with favorable weather conditions.

Ashes of lignite coming from the Konin area contain large amounts of Ca and S, and this content bears on the specific properties of the wastes on the stack. In the course of combustion of calcium compounds, calcium oxide is formed which, during its slaking and hydraulic transport, combines with water giving $Ca(OH)_2$. Combinations of $Ca(OH)_2$ with sulphur or carbon give $CaSO_4$ and $CaHSO_4$ and $CaCO_3$. Because of this, the stack of ashes is a gypsum or a carbonate rock, difficult for biological reclamation. At various stages of the wastes formation, their reaction changes from pH 11-12 to pH 8-9, depending on the time during which the piling up was taking place. As the exposure to air goes on, the superficial layer undergoes the influence of wind or water erosion.

Protection Against Dusting

To provide against dusting by the fly ash during its transportation on a conveyor belt, one wets it up with water.

The treatment of the surface was tested on a laboratory scale with the following substances:

- The asphalt emulsion
- One percent water solution of clutan (waste sulphite liquor)
- Liquid wastes from coffee production
- Molasses
- Phenolic resins reaction waters
- Osacrylate
- Surface active water solutions (detergent solution sulphur solution)
- Diesel oil and oil-water emulsion
- Ethylene glycol

In order to eliminate dust coming from the faces of the stacks, one uses the following with varying success:

- a) Covering with substance-forming films or binding
- b) Biological methods
- c) Combinations of both methods

Covering with film-forming substances consists of binding the surface particles of ash into aggregates or films, preventing their shifting by wind or by streams of atmospheric precipitation. Surface consolidation tests are being made on a laboratory scale in the following ways:

- Through the spraying on of film-producing substances such as asphalt emulsion curosol, osacrylate, oil-water emulsion, water solutions of elastomers
- Through covering the stack surfaces with a layer of mineral soil (fertile soil, sand, clay)

The tested means were required:

- To produce lasting cover in order to prevent dusting
- To be weatherproof
- To be nontoxic
- To be easily accessible, easily affordable, and easy to apply
- To enable further utilization of ashes

Biological methods embrace the consolidation of stack faces with green vegetation (mainly perennial) or arborescent. Most frequently employed for these purposes are grasses and perennial papilionaceous plants.

Attempts to sow seeds directly into the ground met, on the whole, with failure due to the toxic environment--alkaline reaction, salinity occurrence of harmful concentrations of metals and changeable interactions, unfavorable water and air characteristics, deficiency in nourishing constituents, and an absence of soil micro-flora. As a result of observing plant growth, it was established that by adding mineral fertilizers and dressing the seeds with nitrobacteria, the condition of plants was ameliorated. The mineral fertilizers, however, increase the salt concentrations and hinder the shooting. Attempts to plant trees and bushes met with little success on stacks with a neutral or acid reaction, but on stacks with an alkaline reaction such attempts produced rather negative results.

Most often used are biological methods connected with surface binding with substances forming film and preventing dusting prior to plant development. The prerequisite for a chemical consolidation application is that the substance should not be toxic, should not hinder the shooting and growth of plants, and that the film or the consolidated cover should be pervious to air and water.

A mechanical means is being tried to sow out the binding emulsion mixture, the mineral fertilizers, and the seeds with hydraulic or pneumatic systems.

In the course of research work concerning the consolidation of slopes, a positive result was achieved in covering these with transplanted grass carpets, coming from outside of the area. The experiments proved that after two weeks a complete binding of such a carpet with the subsoil took place.

The kinds of plants used were as follows:

Grasses:

- Smooth brome grass (*Bromus inermis*)
- Creeping fescue (*Festuca rubra*)
- Meadow fescue (*Festuca pratensis*)
- Crested wheat grass (*Agropyron cristatum*)
- Orchard grass (*Dactylis glomerata*)
- Sloughgrass (*Beckmania eruciformis*)

Papilionaceous plants:

- Lucerne (*Medicago media*)
- White melilot (*Melilotus albus*)

Trees and bushes:

- Locust tree (*Robinia pseudoacacia*)
- Grey alder (*Alnus incana*)
- Persian walnut (*Juglans regia* L)
- Poplars (*Populus*) some species
- Russian olive (*Elaeagnus angustifolia*)
- Sea buckthorn (*Hippophae rhamnoides*)
- Siberian pea shrub (*Caragana arborescens*)
- Black currant (*Ribes nigrum*)
- Tamarisk (*Tamarix parviflora*)
- Rose-bush (*Rosa rugosa*)

The application of grass mixtures gives the best results. One observes here that within a few years of vegetation, a tendency to form monocultures appears.

Forest Reclamation

Previous attempts to cover the ash stacks with greenery by planting trees and bushes on them can determine a starting point for research on the utilization of regions for the establishment of productive forests or for communal purposes (of a recreational character). In this case, it is important to create habitat conditions for productive trees or for trees possessing ornamental qualities.

After the unsuccessful attempts to introduce trees onto raw ash, attempts were made to cover the entire afforestation area with fertile soil, or to put the fertile soil into ditches 50-80 cm wide. The results of this afforestation vary depending on the kinds of ashes and on atmospheric conditions. In publications, the unsuccessful tests are usually attributed to a passing drought. The lack of relevant long-term research related to forestry is being felt.

In Czechoslovakia, fruit trees were planted on the weak acid ashes, applying a cover of fertile soil (the thickness of the layer was 30-50 cm). Planted at intervals of three x three m were pear, cherry, apricot, and peach trees. In the first year, the condition of the trees was good (without pests and illnesses), and only one cherry tree perished on an inspection plot that had no fertile soil on it.

Agricultural Reclamation

The first attempts to utilize waste stacks for agricultural purposes had, on the whole, positive results. These were obtained from the biological consolidation accomplished by the sowing of grass mixtures. The cultivated varieties of medium or low quality grasses produced crops equivalent in yield to those coming from meadows of the lowest quality. Publications give no data concerning the usefulness of these crops as an animal feed.

Attempts were made in Poland to sow (plant) one-year's cultures on ashes dressed with mineral fertilizers: charlock, rape, wheat, barley, turnip rooted cabbage, mangold, turnip, and flax. Cultures growing on plain ash usually ended in failure, due to a hindered sprouting. Better results were obtained on plots where, for two to three previous years, grasses or mixtures of perennial papilionaceous plants with grasses had been growing. Large

enough concentrations of mineral fertilizers were used (up to 800 kg/ha of commercial fertilizer). Cultures have been sown on nonirrigated plots, on plots with overhead irrigation with the furrow method and with a deep watering method (with drainpipes placed at a depth of 40-50 cm).

A very positive effect of organic as well as phosphorous fertilization was observed. The plants developed a strong root system. It was characteristic of the roots to develop within a five to 15 cm top layer, while further down there was only a layer of lifeless ash. The root mass accumulated over a few years did not undergo humification. The reaction of the top layer (up to ten cm) varied within limits from pH 10 to 12 down to pH 8.5 to 9, but in a deeper layer it remained strongly alkaline. Good results were obtained with an organic fertilizer in the form of a compost, 60-80 Mg/ha. Mineral phosphorous was gradually better utilized by the plants, as the organic compounds were amassing in the ash. On the lignite ashes from the Konin deposit, it was necessary to crush the petrified ash. Crushing a 5 to 20 cm top layer with a ripper allowed the sowing of grasses, lucerne, charlock, and rape.

Difficult, hindered sprouting and the slow development of plants was ascertained. Grasses in the second and third year of cultivation produced crops approaching those crops of meadows having the lowest denomination. The roots, gathered in the loosened up layer, did not disintegrate.

No research was carried out with respect to the determination of the usefulness of crops for human or animal consumption. Further experiments regarding the agricultural utilization of the stack are taking place.

Perspectives for Further Research

No complete conclusions were made in previous research concerning the problem of ash toxicity being harmful to biological life. The salinity, and an excessive amount of boron and heavy metals sulphating all this, may come into consideration. A strong reaction between some kinds of ashes can activate toxic unions of iron and aluminum.

The completed research on biological consolidation and agricultural and forest reclamation, has not as yet been composite in determining the research circumstances (full characteristics of ash properties, climatic and water conditions, atmospheric pollution). Results of characteristic tests of plant material, mineral and organic fertilizers, neutralizers or growth stimulators, air pollution above the experimental plots, and watering the cultures are limited. For these reasons, the usefulness of the up-to-date research results and their implementation is not sufficient. One very rarely finds, for example, a determination of a tested ashes reaction, and, as is known, the reclamation methods will be quite different for a material with a weak acid reaction (pH 5 to 6), compared to ash material with a very strong alkaline reaction (pH 10 to 12). Meanwhile, a protest against polluting the air and water grows in the community with the growing stacks of wastes, and, on the other hand, with the growing value of the terrains occupied by nonutilized piles.

In view of the issues discussed above, the need for complex research arises both in the laboratory and in the field:

- a) To learn the properties of ashes with respect to their utilization or their biological reclamation;
- b) To learn the influence of stacks on atmospheric air pollution, and on surface and ground waters, and also the countermeasures to ward off the damaging effects;

- c) The utilization of stack areas for agricultural and forest production by means of appropriate technological and cultivation applications, or through the adaptation of various cultures to the environmental conditions.

The project carried out in cooperation with E.P.A., referred to as a "reclamation of alkaline ash piles," is to serve the aims discussed above. It was planned in reference to wastes obtained from power plants fired with hard coal and with lignite, and characterized by alkaline reactions. In the sphere of biological reclamation, applications of several neutralizers or growth stimulants, and various combinations of mineral and organic fertilization for various cultivated plants in special reclaiming crop rotations will be provided. Less attention will be given to the problem of securing the stack against dusting, since this issue is already well known.

Full documentation of the composite research will permit the adaptation of positive results to conditions in the U.S.A.

AGRICULTURAL USES OF FLY ASH¹

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Removal of fly ash from flue gases prior to their discharge into the atmosphere has decreased particulate air pollution, but has created a solid waste disposal problem (3). Over 85.4 million metric tons of fly ash were produced in the United States during the 3-year period from 1971 through 1973 and, of this, only 9.8 million metric tons were either sold for industrial purposes or removed from plant sites at no cost to the utility (1, 2). Disposal of the nonutilized fly ash represents a considerable cost to the electric power industry.

The amount of fly ash utilization in agriculture was negligible as compared with other industries during the 4-year period from 1970 through 1973 (1, 2). Experimental results that could lead to greater utilization of fly ash in agriculture are discussed herein. The major thrust of this discussion is to review both beneficial and detrimental effects from incorporation of fly ash into soils prior to crop production. Experimental results reported herein were obtained by the author and co-workers from 1967 to present and from numerous investigations reported in the literature.

Mineralogical and Physical Properties

Fly ash from different power generating plants varies in color from light-brownish gray to dark-purplish gray (5). The darkness of fly ash depends partly on its carbon content. Usually fly ash contains less than 5 percent carbon, but in exceptional cases, its carbon content may be as high as 20 percent (26).

The main crystalline constituents present in fly ash are quartz [SiO_2], mullite [$2\text{SiO}_2 \cdot 3\text{Al}_2\text{O}_3$], magnetite [Fe_3O_4] and hematite [Fe_2O_3] (5, 19, 26). Fly ash particles generally consist of amorphous silica containing varying proportions of microcrystals of quartz, mullite, magnetite, and hematite (5, 26). The particles may be cemented with anhydrite to form aggregates (5). Crystalline components identified in small amounts in some fly ashes are lime [CaO], anhydrite [CaSO_4], gypsum [$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$], dicalcium ferrite [$2\text{CaO} \cdot \text{Fe}_2\text{O}_3$],

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calcite [CaCO_3], anatase [TiO_2], and γ -alumina [Al_2O_3] (19, 26). The cation exchange capacity of fly ash generally ranges from 2 to 4 meq/100g (5, 11). A portion of the cation exchange may arise from isomorphous substitution of aluminum for silicon in mullite.

Mechanical analyses indicate that most fly ash particles fall in the fine sand and silt size range (5, 22, 23, 31). Usually fly ash is similar in texture to a sandy loam or silt loam soil (10, 31). The erosion threshold lies between 9.0 to 11.0 m/sec for the major portion of fly ash and is approximately 5.3 m/sec for the low-density cenospheres that make up 1 or 2 percent of the material (5). Fly ash applied to the soil surface may dry and undergo wind erosion. Prevention of wind erosion is achieved by application of moist fly ash and by incorporation of the material into soil.

Chemical Properties

Fly ash from different coals varies widely in elemental composition (5, 9, 10, 16, 22, 27, 30). Results from these studies show that fly ash contains varying quantities of essential plant nutrients except nitrogen. These elements occur in fly ash as silicates, oxides, sulfates, borates, and borosilicates along with smaller amounts of phosphates and carbonates (4, 5, 9). The soluble salt content of fly ash generally ranges from 1.1 to 3.3 percent (10, 22). Concentrations of soluble salts in fly ashes depend on the source of coal, the lagooning processes, and the length of time that the ash has been exposed to weathering (11, 19). The electrical conductivity, which is commonly used as an index of soluble salt content, ranges from 7.0 to 13.1 mmhos/cm for most fly ashes (10). Fly ash from different power generating plants has a pH in the range of 4.9 to 12.0 (6, 10).

Neutralizing Capacity

The titratable alkalinity of fly ash from 15 power generating plants was determined by Doran and Martens (7). Twelve of the fly ash samples were alkaline in reaction and these samples neutralized from 0.01 to 3.74 meq H_2O^+ /g. Calcium carbonate would neutralize approximately 20 meq H_2O^+ /g under identical laboratory conditions. These data show that fly ash has a lower neutralizing capacity than amendments normally added to soils as a liming material. Nevertheless, increases in soil pH occurred where relatively high levels of fly ash were incorporated into soils (7, 8, 17, 18, 19, 25).

A field experiment was conducted to compare the neutralizing capacity of fly ash and dolomitic limestone (15). Fly ash was selected for the study on the basis of its high neutralizing capacity as compared with other ashes from bituminous coal (7). Application of both fly ash and dolomitic limestone increased the pH of acidic Cecil fine sandy loam (Table 1). During the early portion of the study, the pH of the soil was higher from application of 71.7 metric tons of fly ash than from application of 6.7 metric tons of dolomitic limestone. A higher pH occurred in the soil from application of the limestone during the fourth year of the investigation. These results show that the pH of the soil remained at 6.5 or above for a longer period from limestone application than from fly ash application.

Table 1. Effect of Fly Ash and Dolomitic Limestone on the Ph of Cecil Fine Sandy Loam.

Treatment		Soil pH			
Metric tons/ha	Amendment	1971	1972	1973	1974
----	Check	5.6d*	5.6d	5.3c	5.4e
17.9	Fly ash	6.4c	6.0c	5.7b	5.7d
35.9	Fly ash	6.8b	6.8b	6.2a	6.0c
71.7	Fly ash	7.4a	7.0a	6.5a	6.3b
6.7	Limestone	6.6bc	6.7b	6.6a	6.7a

*Means in columns followed by the same letter are not significantly different at the 0.05 probability level.

Alfalfa (*Medicago sativa* L.) yields were increased during the first year of the investigation from incorporation of either fly ash or limestone into the soil (19). Thereafter, yields were not affected by application of the liming materials. The yield increase during the first year was attributed to a faster rate of establishment of alfalfa due to the increase in soil pH (19). Further research is necessary to identify the pH factor that was responsible for the more rapid establishment of alfalfa.

Ideally a liming material should increase the pH of an acidic soil and supply calcium and magnesium to plants. The fly ash under study increased soil pH (Table 1) and supplied calcium to the alfalfa plants (19). Plant tissue analyses indicated that the magnesium in the fly ash was relatively unavailable to the alfalfa plants (19). Previous research has shown that fly ash from different coals varies widely in its content of plant available calcium and magnesium (17).

Nutrient Availability

Research has been conducted to determine the suitability of fly ash as a source of plant nutrients. The research usually was conducted on soils that supply inadequate amounts of the nutrient under study. This procedure was followed to allow evaluation of data on the basis of plant yield and nutrient uptake. Plant nutrients that received the most attention in these studies were boron, molybdenum, phosphorus, potassium, and zinc.

Boron availability. Data from a greenhouse evaluation study indicated approximately equal plant availability of boron in fly ash and in $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ (18). The latter compound is frequently used to correct boron deficiencies of plants. A field experiment was conducted to determine the effect of fly ash application on boron availability. Incorporation of one application of two fly ashes into Tatum silt loam increased alfalfa yield over a 3-year period (Table 2). The total boron contents of the Big Sandy and Fort Martin fly ashes under study were 232 and 370 ppm, respectively. Data from plant tissue analyses confirmed that the increases in yield were due to correction of boron deficiency (20). Boron uptake data indicated that boron in the fly ashes was readily available initially but decreased with time (20).

Table 2. The Effect of Boron Application as Fly Ash and $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ on Yield of Alfalfa Grown on Tatum Silt Loam.

Boron treatment		Yield*		
Level	Source	1971	1972	1973
kg B/ha			kg/ha	
0.0	Check	1,510b [†]	9,187b	6,873c
1.7	Big Sandy fly ash	3,602a	11,004a	8,743b
3.4	Big Sandy fly ash	3,622a	10,536a	8,863b
1.7	Ft. Martin fly ash	3,322a	10,435a	9,107ab
3.4	Ft. Martin fly ash	3,452a	11,222a	9,542a
---†	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$	3,187a	10,599a	9,329ab

* Total yield for one clipping in 1971 and four clippings in 1972 and 1973.

† Means in columns followed by the same letter are not significantly different at the 0.05 probability level.

* Cumulative levels of application were 3.4, 5.6, and 9.0 kg boron/ha in 1971, 1972, and 1973, respectively.

Molybdenum availability. A greenhouse investigation was carried out to determine the effect of fly ash application to soil on molybdenum availability (7). Seventeen samples of fly ash under study ranged from 5.6 to 39.3 ppm in total molybdenum content. Incorporation of two samples of fly ash, which contained extremes in the range of total molybdenum content, increased alfalfa yield on an acidic Groseclose silt loam. The increase in yield was attributed to alleviation of toxicities associated with low levels of soil pH. Molybdenum uptake data indicated approximately equal availability of molybdenum in fly ash and in $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$. The latter compound is frequently used to correct molybdenum deficiencies of plants. It has been shown that concentrations of molybdenum in forage plants ranging from 10 to 20 ppm can induce molybdenosis in cattle (12, 13). Plant tissue contained an amount of molybdenum in this range where a high level of fly ash was applied to soil. These data suggest that application of relatively high amounts of fly ash to soil could cause toxic levels of molybdenum in forage.

Phosphorus availability. The total phosphorus in fly ashes from bituminous coals obtained from 16 power generating plants ranged from 0.03 to 0.17% (14). The sample with the highest phosphorus content was selected for a greenhouse investigation to determine the effect of fly ash application on phosphorus availability in Landisburg silt loam. Phosphorus deficiency of corn (*Zea mays* L.) plants was corrected by application of 210 mg P as $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ and partially corrected by the same level of phosphorus as fly ash (Table 3). Incomplete correction of phosphorus deficiency was attributed partly to a decrease in corn plant growth due to a high concentration of soluble salts from the fly ash (14). Low availability of phosphorus in fly ash has also been attributed to retention of phosphorus by hydroxides and oxides of aluminum and iron in the material (22).

Table 3. Effect of Fly Ash Application on Phosphorus Availability in Landisburg Silt Loam.

Treatment		Weight of dry tissue g/pot	P conc. in tissue %
Level	Source		
mg P/pot*			
---	Check	8.0c [†]	0.14c
210	Ca(H ₂ PO ₄) ₂ ·H ₂ O	18.8a	0.21b
210	Fly ash	12.2b	0.26a

* The amount of soil used was 2.1 kg/pot.

[†] Means in columns followed by the same letter are not significantly different at the 0.05 probability level.

Potassium availability. A greenhouse study was conducted to determine the availability of potassium in fly ash from nine power generating plants (17). Application of four of the nine fly ash samples increased potassium uptake by corn plants grown on Davidson clay loam. The potassium in the fly ash samples was much less available than an equal level of potassium applied as KCl. The latter compound is frequently used in potassium fertilizer.

Zinc availability. The plant availability of zinc in fly ash from six power generating plants was investigated by greenhouse procedures (25). One of the eight samples corrected zinc deficiency of corn grown on Westmoreland silty clay loam. The fly ash sample that corrected zinc deficiency was acidic in reaction. Although research indicates that zinc availability increases with a decrease in soil pH, experimental results from the study indicated that the fly ash corrected zinc deficiency on the Westmoreland soil by supplying soluble zinc rather than by modifying the pH of the soil.

Soil Moisture

Plant available moisture refers to soil water held in capillary pores and on surfaces of soil particles (28). Available water has been increased by application of fly ash to sandy-textured soils (23, 24, 31). A level of application of 72 metric tons/ha of fly ash increased the plant available moisture in Woodstown loamy fine sand (31). Formation of smaller pores from filling of voids between sand particles with silt-sized fly ash probably was responsible for the increase in available water (31). An increase in available water may be beneficial from the standpoint of reducing the need for irrigation of sandy-textured soil (23).

Tolerable Levels of Fly Ash Application

Experimental data obtained by the author and co-workers indicated that four annual applications as high as 143.4 metric tons/ha of weathered fly ash did not affect corn grain yield on Groseclose silt loam. The fly ash under study was weathered in a lagoon for approximately three years prior to the investigation (21). Application of a much lower level of unweathered fly

ash decreased corn population and grain yield on the Groseclose soil (Table 4). Laboratory and greenhouse data indicate that this decrease in yield was caused by boron toxicity. This finding concurs with experimental results showing high availability of boron in fly ash, both herein (Table 2) and in the literature (5, 10, 18, 23). Decreases in plant growth have also been attributed to a high level of soluble salts from fly ash application (10, 14). The electrical conductivity of the unweathered fly ash (Table 4) was 5.0 mmhos/cm. An electrical conductivity of 3.2 mmhos/cm was obtained where 107.5 metric tons of the unweathered fly ash were equilibrated with the soil for 75 days. Normal growth of corn plants is expected at an electrical conductivity of this level (29).

Table 4. Effect of Unweathered Fly Ash on Corn Population and Grain Yield on Groseclose Silt Loam.

Fly ash application metric ton/ha	Corn grain yield kg/ha	Plant population plants/ha
0.0	7728a*	85,210a
47.8	6941ab	77,200ab
95.6	5682b	63,690b
143.4	3443c	35,880c

* Means in columns followed by the same letter are not significantly different at the 0.05 probability level.

Conclusions

Experimental results discussed herein show that application of fly ash may be beneficial for crop production where the material increases the pH of acidic soil, the availability of an essential element in soil, or the amount of available water in soil. The beneficial effect of fly ash application on increasing the rate of seedling emergence has been discussed elsewhere (23). Indiscriminate application of fly ash to soil is undesirable; for, in some cases, the material may decrease plant growth due to boron toxicity; to injury from a high concentration of soluble salt; to phosphorus deficiency induced by reaction of soil phosphorous with hydroxides and oxides of aluminum and iron in fly ash; and to nutrient deficiencies induced at high levels of soil pH.

Traditionally relatively low amounts of elements such as boron, molybdenum, and zinc have been applied to agricultural soils to prevent accumulations of these elements that subsequently would become hazardous to animals or plants. It seems that it would be appropriate to monitor the elemental composition of fly ash prior to its incorporation into agricultural soils to prevent abnormally high accumulations of these elements. This monitoring probably should include a wide array of elements, for ashes from various coals differ widely in contents of numerous elements (9) that could be hazardous if they enter the food chain.

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OVERBURDEN TOXICITY OF THE LIGNITE OPENPIT MINES
AND METHODS FOR ITS NEUTRALIZATION AS REQUIRED BY
THE STACKS RECLAMATION

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Introduction

Conditions for the reclamation of land transformed by industry depend on the type and characteristics of formations occurring in the superficial layers, on the terrain configuration, on water and climatic conditions, also on the level and the kind of atmospheric air pollutants. The reclamation of terrains with phyto-toxic soils offers special difficulties.

Out of these extensive, extremely complex and not very well understood problems only a few issues were chosen, which are presented in this report regarding lignite mining.

Considered more broadly by the author are toxicity systematics and diagnostics in somewhat more detail.

Diagnostics of Toxicity

The usability of the overburden formations (rock soils) for reclamation requirements adopted in Poland is to be determined by means of the following classification system:

A Class - the very good euthropic formations, good for agricultural cultivation; the land valuation number is $LB > 75$.

B Class - good euthropic formations, less suitable for agricultural cultivation, very good for forest cultivation; the land valuation number is $50 < LB \leq 75$.

C Class - defective or mesothropic formations, useless for agricultural recultivation, can be used for forest cultivation only, after some effected soil amelioration, valuation $21 < LB \leq 50$.

D Class - bad, barren oligotrophic formations, i.e., not productive, useless for recultivation, require substantial fertilization or isolation, valuation $LB \leq 21$.

E Class - toxic formations useless for cultivation, requiring a neutralization or isolation, where one distinguishes the following subdivisions:

EC sub-class - toxic formations, which after applying successful neutralization to it can get a classification of at least a C class.

ED sub-class - toxic formations, which after neutralization can only be classified to the D Class.

The classification of geological formations to an appropriate class is made on the basis of valuation of the results of field and laboratory tests. For nontoxic formations, the following adopted factors are basic to this area:

- 1) The lithogenesis of formations
- 2) CaCO_3 content and eventually also the MgCO_3
- 3) The plasticity index
- 4) The sorption capacity
- 5) The quantity and the kind of organic matter (humus and its forms, peat, brown, coal, lignites, xylites etc.)

A designation of these elements also enables the use of a qualitative--or a so-called points awarding--classification. In this system, a gradation to a certain class follows on the basis of a determined land valuation number (LB), expressed in points (1).

To reach a diagnosis concerning the toxicity, elementary or auxiliary factors will be:

- a. Contents of sulphides, native sulphur, or sulphates
- b. Salinity
- c. Content of the phito-toxic trace elements (viz. B, Pb, Zn, Ca, As, F) and the easily hydrolyzed Al salts
- d. Radioactivity
- e. Response to a thermal activity
- f. Reaction

A reconnaissance of the toxicity should be performed in the course of the geological investigation of the overburden. It would be advantageous to carry out such tests in two diagnostic stages--an initial one and a detailed one.

An initial reconnaissance has as its goal to single out the toxic formations from the other ones, on the basis of an indexo-eliminating test. Such investigations must be adapted to the character of the chemical compounds, which can cause toxicity. Up-to-date experiments indicate that the most widespread source of toxicity in the overburden formations exploited with the openpit lignite mining method in Poland are the sulphides and, strictly speaking, the decomposition of their products, strongly acidifying the medium. Therefore, the indexo-eliminating tests can in many cases be limited to two functions:

1. An establishment of the presence or absence of sulphides and
2. An ascertainment of an excessively acid reaction occurrence.

One has to expect the occurrence of the iron sulphides in all soils formed in a strongly reducing medium, especially near to the coal or inter-coal formations. Significant to the stack formation is the form of the sulphides' occurrence, i.e., pyrite, marcasite, hydrotroilite, melnicovite and others; also the manner of their layout--dispersed, concentrated; and the lithological composition of formations in which they occur--sand, clay--since on them depends the rate and the range of toxicity appearance, effected by the sulphides' decomposition.

The field presence of sulphides or of sulphates can be established, for instance, through the treatment of soil with sodium azide (NaN_3).

The excessively acid reaction (< 3.5 pH), even with a simultaneous ascertaining of the sulphides' absence, constitutes a sufficient criterion to consider that the formations are toxic.

Whereas the lack of a strong indication of acidification can be regarded as recognizing the formation as a nontoxic one, one can be only assured when

no presence of sulphides, sulphates or native sulphur can be found. In the overburden formation, especially in the older geological formations, and originating in the zone of reduction, the reaction is an element of low stabilization; therefore, it can constitute an auxiliary one only and is not the main classification criterion. Very often in a condition of a natural deposition of strata, the formations are not acid, despite a significant content of sulphides, and their acidification appears only as the result of changes in water-air relations after the drainage and open cutting of the deposit.

The other previously mentioned reasons for toxicity on the stacks are most often connected with the wastes of certain minerals, i.e., sulphur, zinc, lead, and copper ores. In such cases, one has to employ individually chosen indexo-eliminating tests. The possibility of a toxicity occurrence of the overburden may be revealed by the chemical composition of ground water.

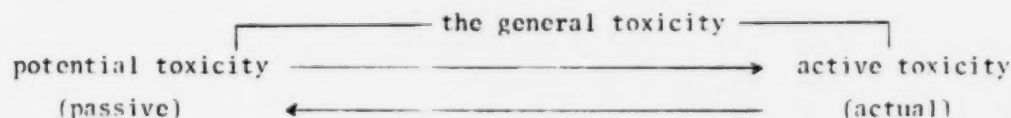
A particular reconnaissance of the toxicity is based on properly chosen laboratory tests confirming or contradicting the initial diagnosis reached in the course of performed field indexo-eliminating tests. The results of these tests must, first of all, facilitate a definition of the causes and forms of a toxicity occurrence. In the case of toxicity caused by the sulphides, minute tests must also consider the determination of the disposition of toxic formations among the nontoxic ones and the determination of the so-called acids and bases balance (2).

The final step in a thorough evaluation of the toxic formations is a classification of these formations into appropriate subclasses EC or ED depending upon their cultivation ability, as defined in (1).

The Chief Forms of Toxicity

The most frequent cause of terrains being formed with phyto-toxic soils is the accumulation of mined and processed wastes, containing on the surface biologically harmful compounds to plants. In the formation of such terrains, as for instance stacks, sedimentation ponds, dumps or others, significant blame falls on the mining industry, particularly openpit lignite, copper ores, and zinc-lead ores mining and the power engineering, metallurgical, and chemical industries. The emergence of toxic terrains is also caused by soil contaminations, occurring for example in regions of strong pollution, by industry of air or water, in regions of sulphur exploitation carried out with a method of underground melting, in regions of salt exploitation, on the routes of crude oil pipelines, etc.

On the basis of past research on the toxicity occurrence mechanism on stacks, for the needs of their reclamation, one can distinguish the following forms of toxicity:

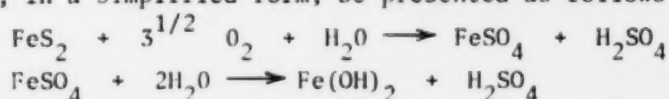


Potential toxicity (passive). The main causes of the potential toxicity of mined out terrains are, first of all, the simple sulphides and their related elements (viz., pyrite, maracasite FeS_2 , pyrrhotite, sphalerite ZnS , Chalcopyrite CuFeS_2 , galenite PbS), salts sulphides, brimstone, arsenides, fluorides,

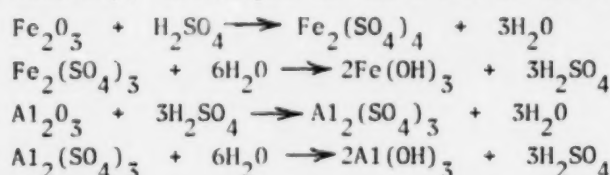
carbonates, oxides and other compounds, having in their composition the bio-chemically harmful trace elements not assimilable to plants. This toxicity, therefore, is connected either with the presence of some trace elements, i.e., Pb, Ca, As, Zn, F, B, Mn or with the possible formation of compounds strongly influencing the chemical mechanism, for instance acidifying, alkalinizing, and reducing. Very often, both of these causes occur simultaneously. Potential toxicity appears only in conditions favoring a decomposition (aeration) of these compounds and the decomposition products passing into the liquid or gaseous phase of the soil medium. Such processes can either take place in the overburden--or after draining or its partial uncovering--or on the stacks before, during, or after the execution of reclamation.

The active toxicity (real). The active toxicity is connected with the increased contents in the liquid or gaseous phase of the soil medium, of compounds harmful in character to the biological processes. Such compounds can also occur in the solid phase, but in a form that easily passes into a solution. Toxicity is being caused mainly by products of a decomposition of these compounds (minerals) which are the cause of the occurrence of potential toxicity.

A typical mechanism of potential toxicity for the overburden of our lignite pits--the sources of which are sulphides--going into the active toxicity phase can, in a simplified form, be presented as follows:

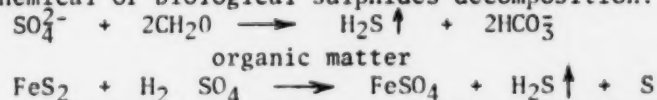


A gradual acidification of the soil medium by the H_2SO_4 activates the potential toxicity, an example of which can be the following processes:



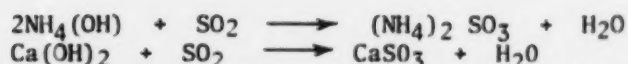
In effect such processes as the easily hydrolyzed salts Al, Fe, Mn translocate themselves and widen the zone of excessive acidification, and also block the phosphorus compound. In a strongly acid environment toxic concentrations of Al and Mn also appear and the physical properties undergo negative changes, especially the water-air characteristics of the overburden formations. An extreme example of this is the acquisition of water-repellent characteristics by the sulphated sands containing a greater coal substance admixture.

Another example of a toxicity appearance can be the formation of hydrogen sulphide, as a result of a reduction in sulphates, or as a result of reactions taking place between the sulphides and sulphuric acid, coming into existence through chemical or biological sulphides decomposition:

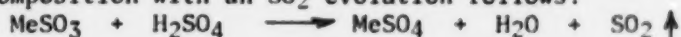


From an elementary sulphur in an oxidizing medium can become SO_2 , as the intermediate product. This strongly toxic gas which is not easily oxidized can occur for a longer period in a gaseous phase in the stack soils (soil air). In alkaline reaction it can form sulphides, according to the following processes:





The sulphites of alkaline metals, as the easily dissolving ones in water, can translocate in the soil. When they find themselves in an acid environment, their decomposition with an SO_2 evolution follows:



where:



Such situations can take place, for example, when for the needs of reclamation only the top layer of the toxically acid formations is being neutralized, and then is being intensively fertilized with potassium or nitrogen fertilizers in an ammonium form. Calcium sulphite, as the difficult soluble one in the water, is comparatively more durable and therefore less toxic.

In strongly reducing conditions, i.e., in the presence of a hydrogen sulphide, sulphur dioxide can pass into elementary sulphur, according to the following scheme:



The oxidation of sulphides to elementary sulphur can also take place with the biological method. Both with the biotic and abiotic processes of sulphides and elementary sulphur changes, a number of intermediate products are initiated, as for instance jarosytes $/\text{KFe}_3/\text{SO}_4/2/\text{OH}/_6$ or alum stone $/\text{KAl}_3/\text{SO}_4/2/\text{OH}/_6/$.

Methods of a Toxicity Liquidation

In a reclamation practice on the stacks of lignite openpit mines, the isolation, the deconcentration and neutralization are the most often employed methods of toxicity elimination. These can be utilized both in the case of a selective and of a nonselective management with the overburden--where the choice of its method depends on many natural and technico-economical factors.

Isolation. Isolation is based on a covering of the reclaimed surface with a layer of soil of adequate quality and thickness. This method can be employed either as an independent, separate one, or in connection with the neutralization of the isolated toxic soil, whereby the isolation can be effected gradually in the course of stack erection or in the course of a reclamatory activity. The obligating legal provisions in Poland impose a duty of soils isolation, such as soils which are considered to be in the subclass ED. The thickness of an isolating layer depends on many things, first of all, on the kind of toxicity and the type of soils used for isolation on the level and distribution of the atmospheric precipitation, and on the direction of the future economic utilization, i.e., recultivation. Employing a proper blockade, positive results were obtained with only a 30 cm thick isolating layer, in the agricultural cultivation of strongly toxic flotational wastes. In the case of forest cultivation, the thickness of this layer must be at least 180-200 cm, but its quality may be poorer.

Deconcentration. This is based on a mixing of the toxic formations with the nontoxic ones in such a proportion, that the concentration of the toxic formations should remain below the toxicity threshold. This is possible when the toxic formations in the overburden concentrate only in determined zones and the openpit work technology affords a proper qualitative choice of soils (composition blending) layered in the top stratum of the stack. This method is also used in some countries to enrich the barren soils (class D) through their mixing with fertile formations.

Neutralization. The neutralization is based on a chemical or a chemico-biological toxicity elimination. This can be executed in two ways.

- 1) Through a direct neutralization of compounds, being the cause of soil toxicity, i.e., H_2SO_4 neutralizing. When required, this application can be connected with an activation process leading to the transition of a potential into an active toxicity process, viz., the sulphides decomposition processes.
- 2) Through a so-called blocking of toxicity, based on the preservation of a durable form which is conducive to developing potential toxicity. When needed, this treatment can be connected with one conducting the active toxicity into a passive one. An example of this can be the phosphate blockade of Al, Fe, Mn compounds, a clay blocking the F compounds, and a lime blocking the Pb, Zn, Cu, F compounds.

The choice of the manner of neutralization depends first of all on the kind and form of toxicity, on the soil type, and on the reclamation direction.

The most effective are the methods in which, as the neutralizing substance is employed, the compounds that simultaneously feed the plants, effect structural formations of the soils, or increase the sorption capacity or the water capacity are used.

In this respect, the tested substances include:

1. The agricultural lime in its forms CaO or $CaCO_3$ and the so-called magnesium oxide lime CaO MgO,
2. The ground phosphate rock and other phosphorus fertilizers,
3. Ammonia water used separately or jointly with the ground phosphate rock,
4. Alkaline fly ashes from the power plants,
5. The raw bentonites or other montmorillonite clays and the sorbent fertilizers obtained on their base.

Lime is the most common but a comparatively little active neutralizer of toxicity. Its doses fluctuate from a few to a few hundred t/ha. It is used in one or two layers neutralization. With very high doses of quicklime, one even observes a periodical petrification of sand-gravel soils.

Considerably better results were achieved with the employment of magnesium oxide lime to the neutralization.

It is a waste product of zinc metallurgy, containing 35-45 percent of CaO and 15-25 percent of MgO, and is rich in numerous trace elements. Ashes from the power plants fired by lignite are being used on a very large scale to reclaim the toxic stacks in Eastern Germany. Best suited for this purpose are the fly ashes containing at least 15 percent of CaO and no more than 4 percent of S. This is used in quantities from 350-700 m^3/ha , in one or two layers.

The results of the executed neutralization are very good, especially when NPK fertilization is also used simultaneously in large quantities.

The best reclamation results achieved in Poland on the lignite mines' toxic stacks were the result of using, as neutralizers, the ground phosphate rock together with an ammonia water or agricultural limestone (Table 1 - combinations F and D). The used ground phosphate rock contained around 30 percent of P_2O_5 and 25-50 percent of CaO in the form of calcite and apatite. The role of the ground phosphate rock is many-sided, the proof of which is seen in the data in Table 1 indicating crop increments in the grass mixture with papilionaceous plants to an order of over 700 percent as compared with the crops obtained from the controlled plots. Of interest is the very large increase of phosphorus in an assimilable form in the soil.

Table 1. Influence of Various Methods of Neutralization on Some Chemical Properties of the Soils and the Crop of Cultivated Plants on the Reclaimed Stack of the Lignite Opencast Mine "Turóg"

Combinations of the neutralization method	Depth of the sample taking cm	pH in KCl	Acidification hydrolytic H_h mval/100 g	Exchangeable acidification H_w mval/100 g	Aluminum exchangeable Al_w mval/100 g	Contents of assimilable P_2O_5 K_2O	Crop of the fresh mass of plants %
The surface covering the plots							
A	0 - 20	3.0 - 4.5	0.50 - 16.60	0.08 - 1.56	0.00 - 3.90	0.4 - 0.5	9.0 - 14.0
		after the first year of cultivation of grass mixture with the papilionaceous plants					
	0 - 10	3.9 - 4.0	6.00 - 9.52	0.16 - 0.70	1.40 - 2.47	0.7	11.4
B	10 - 20	3.7 - 5.3	1.57 - 8.62	0.12 - 1.83	1.06 - 2.70	0.7	13.6
	0 - 10	4.0 - 5.4	1.27 - 9.75	0.02 - 0.22	0.03 - 1.01	0.7	9.9
	10 - 20	3.3 - 3.4	8.10 - 13.65	0.09 - 0.77	2.01 - 4.57	0.6	10.8
C	0 - 10	5.1 - 5.6	1.35 - 3.60	0.00 - 0.05	0.00 - 0.04	0.7	9.0
	10 - 20	4.3 - 4.4	4.95 - 6.67	0.14 - 0.18	0.35 - 0.47	0.7	8.1
	0 - 10	4.9 - 5.6	1.80 - 7.50	0.06 - 0.14	0.02 - 0.38	4.3	9.9
D	10 - 20	3.8 - 5.6	1.72 - 10.95	0.07 - 0.48	0.02 - 2.15	15.7	8.4
	0 - 10	3.8 - 4.3	7.12 - 10.27	0.10 - 0.33	1.42 - 2.40	26.7	11.4
	10 - 20	3.3 - 4.1	7.57 - 10.72	0.10 - 0.54	2.26 - 4.32	1.0	8.7
E	0 - 10	3.9 - 4.2	6.45 - 7.95	0.06 - 0.21	1.08 - 1.72	24.3	7.2
	10 - 20	3.7 - 3.8	7.42 - 8.77	0.32 - 0.49	1.43 - 2.80	1.3	8.4
		without neutralization (controlling plots)					
F	Ca0 in a dose 5 t/ha one layer						ground phosphate rock in dose 3 t/ha, one layer
	Ca0 in a dose 10 t/ha two layers						ground phosphate rock in dose 3 t/ha and 25% ammonia water in dose 5 m3/ha, one layer
	layer 0 - 15 cm 5 t/ha						
G	layer 15 - 30 cm 5 t/ha						
	Ca0 in a dose 5 t/ha and ground phosphate rock in a dose 3 t/ha, two layered						
	layer 0 - 15 cm 5 t/ha Ca0						
H	layer 15 - 30 cm 3 t/ha ground phosphate rock						

Ammonia water can be used only in strictly defined conditions, considering it as an initial neutralizer, for the quick neutralizing of free H_2SO_4 , and as an activator of biological decomposition and the toxic compounds neutralization processes.

A special type of neutralizer is the so-called sorbent fertilizers prepared on a bentonite base (3). Their application gives excellent results in a reclamation of the chemically contaminated sandy soils. The employment of sorbent fertilizers must be preceded by an excessive acidification elimination.

A separate issue is the determination of the quantitative requirements of the employed neutralizers, and doses of the fertilizing mineral, especially of phosphorus, in such cases, of course, where no phosphorus compounds are being used as the basic or as the supplementary toxicity neutralizer. The experiments indicate that most often the generally used methods for similar purposes in pedology or in agrochemistry are disappointing. In the case of toxically acid soils, the best effects were obtained when the determination of the neutralizer doses were based on a definition of the results of the so-called acids and bases balance.

Symptomatic characteristics of the lignite open pits overburden stacks are not only the large deficiencies of nitrogen, but also of phosphorus. The lack of phosphorus always occurs on the toxically acid and on the toxically alkaline stacks, and its liquidation is not easy. Phosphorus contained in the mineral fertilizers gets quickly immobilized; therefore, defining the suitable requirements and ways of administering the dosage of these fertilizers should be based on adequate methods of laboratory research. This is an equally important issue compared to the issues concerning the proper selection of vegetation and the agrotechniques of cultivation on reclaimed toxic stacks.

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COAL WASTE STABILIZATION BY ENHANCED VEGETATION

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Abstract

Coal wastes generated by previously uncontrolled surface mining and dumping of preparation plant refuse continue to cause environmental and aesthetic problems. One potential method of treatment developed by the United States Bureau of Mines employs powerplant fly ash as a soil-building amendment. Application of tonnage quantities of fly ash has resulted in successful revegetation of experimental sites totaling 83 acres of orphaned surface mines and 59 acres of refuse material. Costs include regrading, mixing of ash and spoil, seeding, fertilizing and mulching, but are highly dependent upon haulage of fly ash.

Introduction

Coal wastes in the form of surface mine spoils and preparation plant refuse without adequate reclamation may defile the landscape in coal mining areas. Burning refuse banks pose a health hazard to area residents, produce defoliation of certain vegetation and cause local property damage. Other refuse banks are potentially harmful from acid drainage, erosion and sedimentation, and landslides. Surface mine spoils also generate acid mine drainage, erosion and sedimentation, and in some cases, landslides. These problems coupled with aesthetic considerations and emphasis on land use make the stabilization and restoration of these areas a challenge to today's environmental and mining technology. The goal is to reclaim these waste areas to higher uses under acceptable economic constraints.

Establishment of vegetative cover on each of these areas through sound reclamation procedures is essential to maintain effective control of erosion and stream pollution. Revegetation of areas where adverse conditions such as

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steep slopes and highly acidic spoil materials occur is not always accomplished without major regrading operations and treatment of the spoil with soil amendments. Maintenance of a proper balance of physical, chemical and biological factors is essential to the satisfactory survival of planted species. Amendments such as lime, fertilizer, and mulch have become commonplace; much attention has been given to the utilization of waste materials such as compost, sewage sludge, manures, and bark as potential amendments. This paper describes a procedure whereby coal waste areas can be stabilized and restored with the aid of fly ash, a byproduct of electric power generation.

Research Background

The fly ash reclamation technique of the U.S. Bureau of Mines has been developed from the continuing program for utilization of powerplant fly ash -- the byproduct of coal-fired electric generating stations. This program has sought to develop tonnage uses for fly ash, a material which is produced at the rate of approximately 35 million tons/yr.

Initial studies (1-3)^{1/} at the Morgantown Energy Research Center into the application of fly ash as a soil amendment for reclamation of surface mine spoils were begun in 1964 with greenhouse experiments. In 1965, the first small scale (1/10 acre) field experiments were started. The successful revegetation of this previously barren surface mine spoil demonstrated that an alkaline fly ash could be used to neutralize highly acid spoils and potentially stabilize these areas against erosion.

Following the initial successful tests, a series of greenhouse and field investigations was made utilizing fly ashes from various sources to treat several different types of surface mine spoils. This series resulted in the successful revegetation of approximately 71 acres of orphan spoils (4-9). Large scale tests on the stabilization of refuse disposal areas were begun in 1970 with the treatment of one (1) acre of refuse material with a mixture of fly ash and municipal sewage sludge. Since that time, in-house and cooperative projects have resulted in the reclamation of an additional 10 acres of surface mine spoil and 49 acres of refuse areas including 5 acres of an anthracite culm bank. These field projects have consumed a total of 36,700 tons of fly ash. Table 1 summarizes the basic data for these test sites, located as shown in Figure 1.

Generally, the surfaces of these sites had weathered sufficiently to provide stable conditions prior to application of fly ash, so little regrading was required.

A current project at a 33-acre site near Albright, West Virginia, will test the application of fly ash to a freshly regraded, acid orphan spoil. Additional work at this site will test methods for distribution of fly ash on spoils by bulldozer, scraper and spreaderbox.

The beneficial effects of reclaiming with fly ash are given in Table 2. In considering fly ash for a specific application, the most important property is the neutralizing ability of the fly ash since acidity is the principal limiting factor in the survival of vegetation on spoil and refuse. Next in importance is the change in soil texture, which affects pore space volume and

^{1/} Numbers in parenthesis refer to references listed at end of paper.

Table 1. Fly Ash Treatment of Coal Waste Areas

Site	Yr. Init.	Type*	Acres	Original pH	Application rate T/acre	Ash pH	Source of ash	Avg. current pH of site	Present condition of vegetation
Albright No. 1	66	SM	1	2.6-3.3	200-800	11.4	Albright	5.6	Excellent
Ft. Martin	68	SM	5	3.1-4.7	150	11.9	Ft. Martin	6.9	Excellent
Shannopin	71	RD	10	Variable	Variable	11.9	Ft. Martin	7.4	Good
Stewartstown	70	SM	65	2.5-3.3	150	11.9	Ft. Martin	7.7	Excellent
Cassville	71	RD	7	3.0-3.8	150	11.9	Ft. Martin	6.0	Excellent
Bunker	70	RD	1	2.7-3.0	150	11.9	Ft. Martin	7.1	Excellent
Century	73	RD	20	2.7	200	11.5	Harrison	6.8	Poor
Powhatan Point	72	RD	6	2.8	200	9.1	Berger	7.4	Good
Rex Coal Company	73	SM	10	4.5	200	11.5	Harrison	7.2	Fair
Ashley	73	RD	5	3.1	300	3.8	Hunlock Creek	6.8	Fair
Westover	65	SM	1/2	2.3-3.8	Up to 600	11.4	Albright	5.1	Good
Albright No. 2	74	SM	33	3.1					
Caldwell, Ohio	74	SM	6	2.6					

*SM = Surface mine spoil

RD = Refuse bank or gob pile

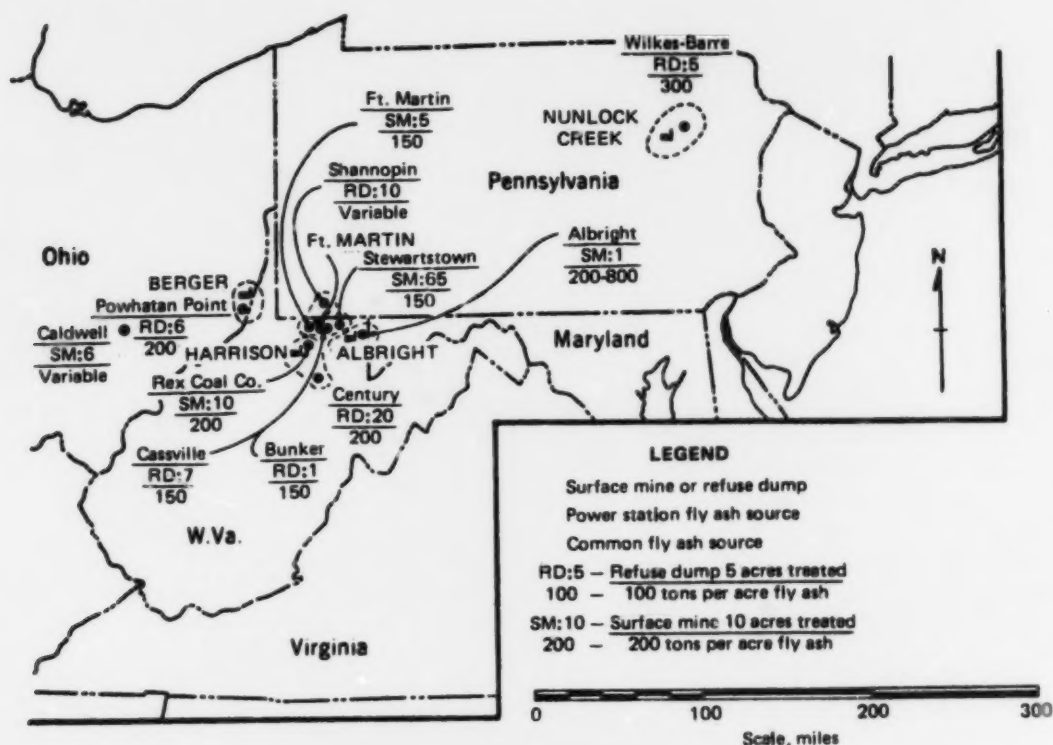


Figure 1. Surface Mine and Coal Refuse Areas Treated with Fly Ash.

moisture-holding capacity. The establishment of plants on the treated spoils provides organic matter to help form soil-enriching humus.

Table 2. Beneficial Effects of Reclaiming Spoil and Coal Refuse with Fly Ash.

1. Acidic materials in spoil and refuse are neutralized.
2. Heavy clay and light sandy soils are changed to medium-texture soils.
3. Moisture-holding capacity and pore-space volume of the surface layer are increased.
4. Grasses and legumes establish an immediate cover that resists erosion and reduces stream pollution potential.
5. Forage yields from fly ash-reclaimed areas compare favorably with undisturbed pastures and fields.
6. Tonnage amounts of fly ash are consumed.
7. Some available major and trace plant nutrients are added to soil cover.

Fly Ash Reclamation Technique

The basic treatment procedure developed from this experimental program consists of several steps beginning with sampling and analysis of both waste material and the available fly ash. From these analyses, application rates are recommended. Fly ash is delivered to the site and unloaded at specified points to ease spreading requirements. The fly ash is blended into the top six inches of the surface material by plowing, scarifying, ripping or the like. A seed bed is prepared, seeded, fertilized and mulched where necessary.

Before a site is treated with fly ash, the area must be leveled and/or contoured, toxic materials buried, land surveyed, and soil samples taken. Soil samples are analyzed to determine acidity, pH, moisture-holding capacity, nutrient deficiencies or fertilizer requirements, soil salinity, and textural classification (screen analysis). Samples of soil should be representative of the area from which they were obtained. This information will help evaluate the area for potential reclamation with fly ash.

Fly ash samples from area power plants are analyzed for alkalinity, pH, conductivity, texture, and chemical analysis. Selection of the fly ash for use in the particular site treatment is then based upon evaluation of these properties and upon the distance of the power plant from the reclamation site. Location becomes crucial as hauling costs will greatly affect the overall fly ash reclamation costs.

The amount of fly ash that is applied to the surface of an area depends upon the relative acidity of the spoil and upon the neutralizing power of the fly ash. It should be emphasized that spoils and fly ashes vary over a wide range with regard to these values. This is readily shown in Table 3, a comparison of fly ashes considered for utilization on various potential demonstration sites. The acidity of the spoil and the alkalinity of the fly ash can be established by titration or by measurement of pH. For most cases the latter method is more rapid and is the one used by the Bureau in working with these materials. However, the titration method will yield a more accurate indication of the neutralizing potential of the fly ash.

The amount of fly ash to be added to a spoil is determined empirically by measuring the pH of various fly ash-spoil mixtures (e.g., 0, 10, 20, and 30 percent by weight) and plotting the results. Such a plot is shown in Figure 2. In this idealized situation the pH of the untreated spoil (zero percent) is 3.0, pH of the 20 percent mixture is 4.0 and pH of the 50 percent mixture is 7.0. Thus, the spoil in this particular case would be treated with the number of tons of fly ash equivalent to the percent fly ash treatment or 500 tons per acre.^{2/}

Since the amount of fly ash required will depend upon the characteristics of both the spoil and the fly ash and because these are quite variable, the percentage of fly ash used in the test mixtures may have to be raised or lowered accordingly to obtain the desired pH level of 7.0.

After the fly ash has been delivered to the site, it is spread in as even a layer as possible to give the desired application rate. The thickness of

^{2/} The average weight of soil in the plow layer (6 inches) is 1,000 tons/acre. Therefore, the 50 percent fly ash treatment would be 1000×0.50 or 500 tons per acre.

Table 3. Comparison of Fly Ashes Analyzed for Application in
Bureau of Mines Field Reclamation Demonstrations

Power Plant	Fort Martin	Albright	Harrison	Berger	Philo	Hunlock Creek	Willow Island	Kincaid
Major elements, wt. pct.								
SiO ₂	46.8	46.3	60.8	49.7	49.9	57.8	51.0	42.8
Al ₂ O ₃	23.3	23.9	19.5	23.7	23.7	26.2	22.6	18.1
Fe ₂ O ₃	17.5	22.9	10.0	17.0	19.3	7.3	17.2	26.7
CaO	5.7	1.9	2.0	0.3	1.0	0.3	1.2	3.5
MgO	1.1	0.8	1.2	0.2	1.3	1.4	1.0	1.7
Na ₂ O	.8	0.6	0.6	0.6	1.0	0.1	0.6	0.4
K ₂ O	2.0	2.2	2.9	2.5	3.8	2.4	2.2	3.5
TiO ₂	.7	0.9	0.5	0.6	0.2	1.4	0.1	1.4
P ₂ O ₅	.5	0.3	0.3	0.1	0.1	0.3	0.1	0.6
C	1.5	5	1.0	3.7	-	38.1	-	2.17
S	.4	0.24	0.52	0.16	0.15	0.34	0.17	2.55
Loss on ignition	5.1	-	1.50	6.26	-	43.3	-	-
Trace elements, %								
B	.045	.008	-	.005	.009	.004	.010	0.203
Cu	.004	.020	-	-	-	-	-	-
Mn	.020	.030	.06	.006	.030	.015	.019	.060
Mo	.002	.007	.31	.00	.009	.008	.010	.037
Zn	.009	-	.02	.011	.047	.009	.008	0.215
pH	11.9	11.4	11.5	9.1	7.7	3.8	7.6	2.5

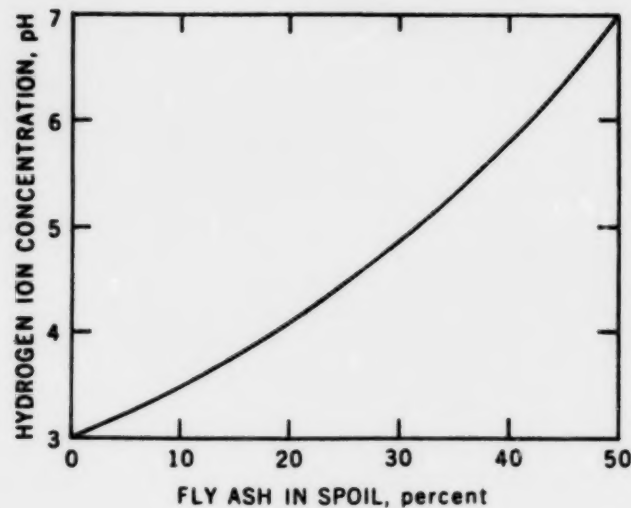


Figure 2. Typical pH Values for Various Spoil-Fly Ash Mixtures.

the layer will depend upon the bulk density of the fly ash as received on the site.^{3/} Spreading can be done by dozer, front-end loader, or other equipment that may be available for such purposes.

Mixing of fly ash and spoil is accomplished by plows and discs. Time and care should be taken during this part of the operation to achieve adequate mixing of the two materials. To accomplish this, it may be necessary to plow the area several times (even in opposite directions), depending on the fly ash application rate. During the last plowing operation, the plow should be followed by a culti-packer or drag to prepare a good seed bed suitable for grass seed.

The nature of the waste materials, the fly ash, and the surface conditions of the site dictate the choice of machinery to be employed. Farm machines, such as tractors, plows, chisels, harrows, discs, spreaders and packers have been effectively used where spoil or refuse was not too rocky or compacted and the terrain suitable. At other sites, heavy construction-type equipment, including bulldozers, front-end loaders, rototillers, rippers and Romc plows, has been required to work the soil because of excessive compaction of surface material, large rocks and uneven terrain. Large dump trucks of the type commonly used to haul coal have been utilized to deliver the required quantities of fly ash over the site.

Seed application rate generally utilized was 45 pounds per acre. Both dry seeding and hydroseeding methods are acceptable and a mulch is recommended on all slopes. Although seeding may be done almost anytime, the chances of success are best if it is done in the early spring or autumn. If seeding is done in mid-summer, a mulch is highly recommended even on flat areas.

^{3/} One inch of fly ash with a bulk density of 70 lbs/cu ft is equivalent to 127 tons/acre.

The amount of fertilizer required on a treated site should be determined by laboratory analysis. In general, a minimum of 1,000 pounds per acre of 10-10-10 analysis fertilizer is recommended or any equivalent substitute is acceptable at the time of treatment. The appearance of the vegetation during the first two seasons should be evaluated for color, vigor, and growth. If the condition is poor, additional fertilizer application is recommended as determined by laboratory test.

The grasses most successfully used on the fly ash-treated plots are given in Table 4. Birdsfoot trefoil (Empire variety), a legume, also gave good results. The symbiotic nitrogen-fixation activity between legumes and root nodule bacteria is well known, and the use of these plants is encouraged to buildup and maintain nitrogen fertility of the reclaimed land, especially where application of chemical fertilizers is impractical.

Table 4. Typical Grass Seed Mixtures Sown on Fly Ash-Treated Spoil or Refuse

Seed	Weight-percent
Kentucky 31 fescue (<i>Festuca arundinacea</i>)	35
Red top grass (<i>Agrostis alba</i>)	14
Orchard grass (<i>Dactylis glomerta</i>)	18
Rye grass (<i>Lolium perenne</i>)	28
Birdsfoot trefoil (<i>Lotus corniculatus</i>)	5

Plant and Tree Survival Problems

A problem sometimes encountered in the reclamation of many coal waste areas has been the relatively high salt content which contributes to poor survival rates for some grasses and legumes. One such case is the demonstration site at Century, West Virginia, a leveled twenty-acre refuse bank which was treated with fly ash in 1973. Even as the refuse was being treated large areas of whitish crystalline material formed on the surface. Survival of the seeded mixture appeared extremely poor over much of the area. Sample pots prepared at Century and returned to the greenhouse for testing have shown that high rates of watering yielded successful growth of the planted species. This would indicate that leaching of the high salt content stimulated growth.

A potential method for developing a cover crop before the salts are leached out would be to utilize salt-resistant species in the grass mixture.

With this in mind, seeds of several species of plants known to have good tolerance for saline and/or alkali soils were tested for germination, growth, and survival on ten-by-ten foot plots treated at a rate of 150 tons of fly ash per acre. Those species showing the best survival were Empire birdsfoot trefoil and yellow sweet clover. Satisfactory results were obtained from intermediate wheat grass and common goatsrue. These species will be evaluated on a larger scale and in comparison to standard species.

The question of tree survival and growth on spoils treated with fly ash has been brought up many times. Several cooperative studies have been conducted with the U.S. Forest Service and West Virginia University Department of Forestry.

The initial attempts to establish tree and shrub seedlings met with little success. Many of the species, when planted soon after the fly ash was applied, died during the first growing season. Those that survived usually died during the second year. At one site, which had been treated with fly ash four years before the trees were planted, some species survived very well. It has been speculated that weathering and leaching may have contributed to the success of the surviving trees.

Species surviving at rates better than fifty percent were crabapple, red oak, European alder, Scotch pine, and Norway spruce, with the alder showing the best growth.

Additional plantings have indicated numerous variables which will have to be investigated further to determine the survival of trees planted on fly ash-treated coal wastes.

These include the following:

1. Condition of the spoil before treatment,
2. Fly ash sources and the rate of application,
3. Establishment of an herbaceous ground cover before planting,
4. Fertilization treatment and the composition of the herbaceous ground cover seeded before planting,
5. Time interval between fly ash treatment and planting, and
6. Species of trees or shrubs planted.

Fly Ash Reclamation Costs

Reclamation costs per acre depend on many variables, including the terrain, mine soil type and age, acreage, equipment used, and degree of reclamation. Based on experience to date, the cost of vegetating areas devoid of growth with grasses is estimated at about \$500 per acre as given in Table 5. According to the Department of Natural Resources of the State of West Virginia, the 65-acre site which served as a basis for this table is one of the worst in northern West Virginia. It had been previously "leveled" for a flat fee, and some additional machine time had to be subsequently expended to provide access roads. The latter work is included in spreading and ripping costs. Fly ash costs depend on the quantity needed to neutralize a particular spoil with a given fly ash and the distance from the powerplant to the reclamation area. Fly ash for this project was obtained without charge; cost reflects transportation charges only. Spreading and ripping (mixing) charges are actual and would vary with the type of equipment used.

The four-state area produces nearly 8 million tons of fly ash per year. Much of this ash is produced in close proximity to the leading counties for strip coal production in each of the states. There is great potential for utilizing fly ash in reclamation in this region by employing the back-haul concept wherein trucks that haul coal to the powerplant deliver fly ash to the surface mine area on the return trip. A mutually beneficial arrangement between the coal operator and the power company provides the operator on the one hand with a material that aids in reclamation and on the other hand gives the power company the opportunity to usefully dispose of a troublesome waste product.

In many cases the fly ash can be obtained for a nominal loading charge and the cost of transportation from the plant to the site. If the back-haul concept is applied, the hauling cost can be considerably reduced over the straight haul charge.

Seeding, fertilizing and testing costs obviously are negligible compared with the three major cost items--fly ash delivery, fly ash spreading, and cultivation. Since reclamation by fly ash treatment is related only indirectly to the leveling method, as would any other reclamation procedure, these costs are not included in the overall estimate.

Table 5. Reclamation Cost of Surface-Mined Spoil^{1/}

Item	Cost per acre	Percent
Fly ash ^{2/}	\$187.50	33
Spreading and ripping ^{3/}	176.00	38
Fertilizer ^{4/}	75.00	16
Seed ^{5/}	26.53	6
Fertilizing and seeding	16.50	4
Soil testing	15.00	3
	<u>\$496.53</u>	

1/ Land acquisition, leveling and supervision are not included.

2/ 150 tons fly ash per acre at delivered cost (10 miles from power station) of \$1.00 per ton. (Fly ash provided at no cost.) \$0.25/ton loading fee.

3/ Eight hours of machine time per acre at \$22 per hour.

4/ 1,000 pounds of 10-10-10 per acre.

5/ 45 pounds of seed mixture per acre.

Estimates in the surface mining industry range from \$700 to \$1,000 per acre--\$500 for earth moving and \$200 to \$500 for seeding, fertilizer, and soil conditioning. Assigning a loading fee of \$0.25 per ton of fly ash at the power station and assuming a hauling charge of \$0.10 per ton per mile, the cost of delivering 150 tons of fly ash to a site 10 miles away would be \$187.50. However, a closer examination of the \$187.50 per acre cost ascribed to fly ash indicates that the actual market value of materials found in the ash and added in the reclamation totaled \$980.80, as assessed in Table 6. Although these ingredients would not be purchased in this form and, indeed, not all of these materials would be in a plant available form in fly ash, the exercise emphasizes additional values for fly ash.

Costs in restoring refuse dumps are also attractive. The standard practice is to cover the refuse with from 6 to 24 inches of earth, which is 1,000 to 4,000 tons per acre, at a cost of about \$1.00 per ton. Since leveling, fertilizer and seed costs would be similar in either case, the same results can be accomplished with 200 tons per acre of fly ash. The savings are obvious and additional land does not have to be disturbed to obtain borrow material.

Although these costs should be confirmed on a much larger scale, it appears that the fly ash technique can successfully compete with other spoil reclamation methods and is much cheaper than soil cover for most coal refuse piles.

Increased interest and participation of coal mining and power generating companies in promoting fly ash for reclamation of waste areas will lead to more information on reclamation practices and costs.

Table 6. Equivalent Cost of Materials Found in Fly Ash

Material	Percent	Amount of 150-ton application	Market Value
CaO	6.8	10.2 tons ^{2/}	\$ 66.30
K ₂ O	2.0	6,000 lb ^{3/}	
P ₂ O ₅	.5	1,500 lb ^{3/}	562.50
Trace elements	800(ppm)	240 lb	
Fine sand & silt ^{1/}	85.6	128 tons ^{4/}	352.00
			<u>\$980.80</u>

^{1/} 100 - 14.4 percent (sum of lime, fertilizer, and ignition loss = 85.6 fine sand).

^{2/} Lime at \$6.50/ton.

^{3/} Fertilizer at \$75/1,000 pounds.

^{4/} Fine sand and silt at \$2.75/ton.

Conclusions

Coal waste areas can be stabilized successfully by treatment of the surface with tonnage quantities of fly ash and vegetating with grasses and legumes. Where plant growth has been inhibited in some instances by high salt content of the fly ash-spoil mixtures, weathering appears to remedy the adverse conditions.

Reclamation costs are highly dependent upon haulage distances for the fly ash, but are generally much cheaper than borrow material.

Tree plantings on fly ash treated areas are more effective when a healthy ground cover has been established first with grasses and legumes.

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POSSIBILITIES FOR UTILIZING AND LIMITING
SELECTED BY-PRODUCTS
HARMFUL TO THE ENVIRONMENT

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Introduction

The various branches of industry require larger and larger amounts of raw materials enriched by means of washing. As a result, great quantities of wastes are produced in the form of a fluid or semifluid pulp. The liquid character of such wastes requires that they be stored most frequently in large sedimentation basins, and this has led to the occupation of significant areas of usable lands (cultivated fields and forests). Rarely does a piling up of the liquid waste materials in old open pits or on waste lands take place.

Regions taken over for the building of sedimentation basins for wastes are most often excluded for other uses for many years.

Some of the wastes can form a secondary raw material, required by agriculture, or in the production of building materials.

The main obstacle in waste utilization is their fluid or semifluid character, making it difficult to work these with excavators and to transport the material by normal transportation means.

Moreover, the wastes deposited in a sedimentation basin often constitute a menace to the surroundings and contaminate the natural environment.

The purpose of this report is to discuss the directions of washed and floatational waste utilization, and the possibilities of limiting the devastated terrains by storing such wastes and controlling the sedimentation procedure.

The General Characteristics of the Wastes

The technological opportunities of industrial wastes utilization--both washed and floatational--depend mainly on their chemical and granulometric composition and on the technology of their deposition in the sedimentation basins.

The chemical waste composition is related to the chemical composition of the raw material and to the enrichment and washing technology. This is the first link, whereby adding components rationally, we can obtain waste material less or more contaminating to the environment, less or more useful to economic utilization.

The granulometric wastes composition is the result of adopting a basic process which could be floatational or washing. A tendency in the floatation procedure is toward the greatest comminution in grinding rocks containing the raw material (granulation below the 0.05 mm), thus facilitating its washing out but generating considerable difficulties in sedimentation and later the desiccation of deposited sediments.

As an example, postfloatational sulphur wastes possess a decisive majority of the dust fraction (more than 90 percent of grains with a diameter of 2-50 microns) and about 10 percent of the clay fractions (grains under the diameter of 2 microns) as shown in Figure 1. Therefore, from the viewpoint of graining, one can characterize these wastes as dusts or dusty clays which, of course, does not mean that they should also possess physico-mechanical properties corresponding to similar soils. To a large extent, this influences the technology of their sedimentation in the sedimentation ponds.

Physical Parameters of Sediment from the Basins in Ogorzelec (Average)

Type of Formations	Specific Gravity	Weight by Volume	Natural Humidity %
I Zone A Dyking	2.78	--	19.24
II Zone B Intermediate	2.62	1.70	34.67
III Zone C Central	2.60	--	37.50

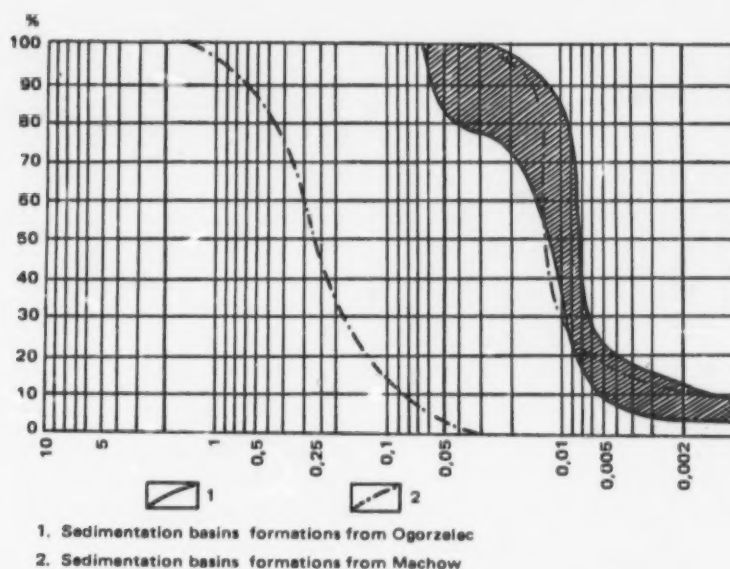


Figure 1. Extremal Diagram Curves of Sedimented Matter Graining.

The most universally employed technology of sedimentation, shown in Figure 2, is generally based on the exploitation of a natural or artificial sink or a depression in the ground, and, in case of either, on an embanking of a certain area, and then constructing within its central part an overflowing tower with a systematically raised level for water overflow. Fluid wastes conveyed from the floatation installations are being brought into the sedimentation basins at a few points spaced along the dikes. Here, the segregation of the waste material takes place, based on the precipitation of larger grains near the banks and smaller ones near the middle of the basins.

Also used--though not often--is the technology shown in Figure 3. It is a very economical technology but contains in itself a danger of breaching the embankments. Its general outlines are based on a periphery of a future sedimentation basin with a low (about one m high) embankment of chamber type to which pulp is brought in from the floatation plants. Large grains precipitate in the chambers, and the small ones flow with water into the central part of the sedimentation basin, where their precipitation follows. The purified water overflows into the overflow tower. The precipitated material in particular chambers is used for raising embankments, and then, in turn, the cycle is repeated till the basin reaches its full height.

Similarly, as in the previous case, the coarser fractions precipitate on the periphery of the precipitation basin and the fines precipitate in its central part.

As a result, in both cases in the central part of the sedimentation basin a pulp constituting, on average, half of all precipitates is formed.

Such sedimentary matter retains a fluid character, sometimes presenting a menace to the surroundings, making reclamation of the covered terrain impossible, and utilization of the sediment for economic use. The reason for this is that the water contained in the sediment and atmospheric precipitation accumulates in the depressed bowl of this sedimentation basin which prevents surficial runoff. The impermeability of the sedimented material makes the draining off through the banks, or to the soil, impossible. Moreover, some of these wastes as, for instance, the postfloatation sulphur deposit are characterized by a strong chemical activity, as shown in Table 1. Characterized by entirely different properties are the sediments derived from the natural and crushed aggregates washing process. These are, on the whole, chemically inactive and also possess a completely different granulometric composition. In waste granulation derived from a crushed aggregate washing, it appears that 40 percent of grains have 8 to 2 mm granulation, 40 percent of grains are from 2 mm to 50 microns, around 15 percent of the grains are 50 + two microns, and only about five percent of grains are smaller than 50 microns.

Table 1. Chemical Composition of Wastes According to Data of K.K. and Z.P.S. Machów -- Average.

Components Collector	S	CaO	CO ₂	SO ₄	SrO	MgO	Fe ₂ O ₃	SiO ₂	BeO
Machów	3.24	46.96	35.85	1.81	0.34	0.23	2.45	5.60	0.09

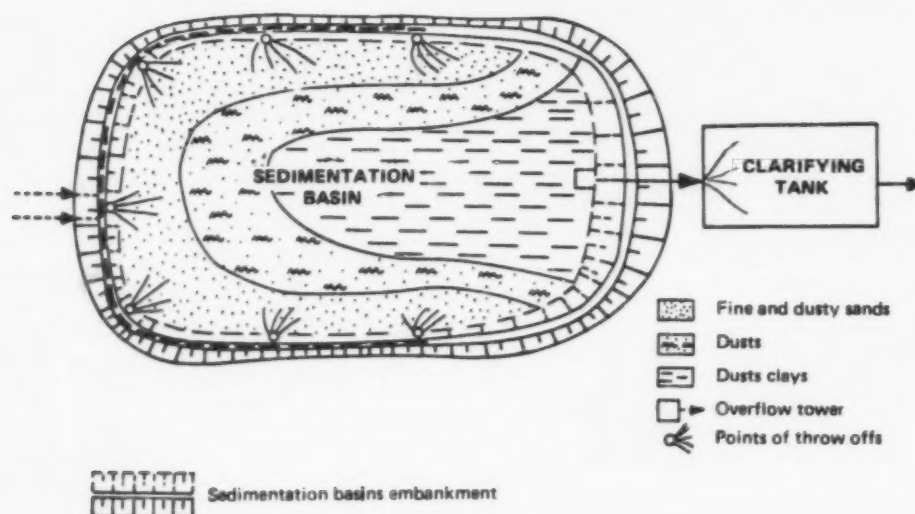


Figure 2. Scheme of a Typical Sedimentation Basin of After-Floatation or After-Washing Wastes in the Terrains Depression.

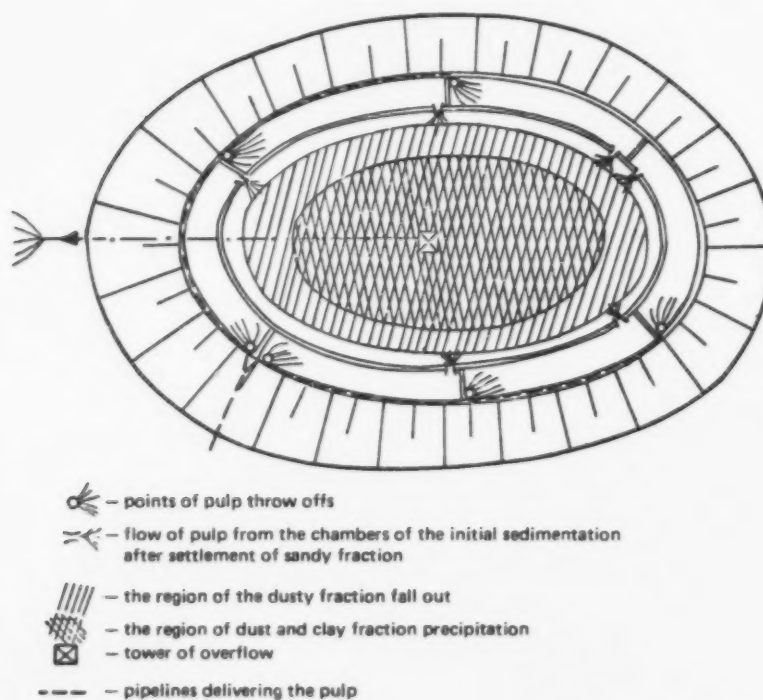


Figure 3. Example of Sediment Basins Dykes Formation With Zone Coarse Fractions (Chamber System).

In its granulometric respect such sediments can be classified as the clay mine-runs. In Poland the technology used in dumping is based on the sedimentation of all combined fractions in one basin, which makes them economically useless, and in addition difficult to filter off.

The Potential Courses of Selected Wastes Utilization

A number of factors exist, demanding increased utilization of wastes, but also factors exist countering such use. In the first case, we can list the increasing number of sedimentation basins of fluid wastes, covering large areas of usable terrains, and also the growing demand by industries for all sorts of possible waste products. Also significant is the issue of water (Table 2) and air contamination by some of the wastes, and this, especially, forces the industrialized countries to actively limit such developments. In this instance, whatever can be used is worthwhile and ought to be employed even when the product obtained from the waste is more expensive than a similar one derived from natural deposits.

An entirely different problem is the case of waste utilization in nonindustrialized countries, or when wastelands exist that can be used for dumping. In such an instance, the issue of costs connected with their utilization can be of paramount importance. The essential conditions of waste utilization, especially wastes of a fluid character are obviously the technical possibilities of their desiccation and operation.

Thus, the possibilities of working and of draining off the wastes developed during the floatation and washing process, and the directions of their economical usability, are the subject of strenuous research. The problem of utilization of waste products is a choice of its own individual merit.

Postfloatation wastes of sulphur ores, researched by the author, occurring in Miocene limestones, contain 70-90 percent CaCO_3 (Table 3), and are mainly useful as deacidifying soil fertilizers, enriching the soil with so-called microelements (trace elements required for proper plant growth). The sizable (three to five percent) sulphur content presents no handicap for agricultural expediency, but eliminates the use of such wastes for building material production.

Kind of Water	Components %	Dry Residue mg/l	Suspended Matter mg/l	p.H.	Total Hardness degr. n.	Fe^{+2} Fe^{+3} mg/l	Cl^1 mg/l	Ca^{+2} mg/l	Mg^{+2} mg/l	SO_4^{+2} mg/l	$\text{N}^{\text{no}3}$ mg/l	Mn Total mg/l	Al^{+3} mg/l
Superficial Water--Basin on Top		1190	30	7.6	47	--	6.02	342.0	0	705.6	--	0.15	--
Water from the Cathode Beginning of Tests		4225.4	1524.8	10.6		--	--	traces	1.6	509.6	--	--	--
Water from the Cathode After 3 Days		5335.6	4017.2	12.4		--	--	0.4	2.3	105.6	--	--	--
Water from the Anode After 10 Days		49152.0	18144.4	3.7		--	976.9	141.0	0.8	4368.0	--	--	2749.3

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						mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
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Table 3. Content of CaCO₃ in Particular Types of Formations -- Sedimentation Basin Machów

Types of Formations	Number of Observations Made	Content of CaCO ₃ %	
		Extreme	Average
I (Zone A)	8	69.0-89.9	83.1
II (Zone B)	16	53.1-82.5	69.3
III (Zone C)	2	53.1-55.3	54.2

Somewhat different is the case for wastes utilization derived from aggregate washing.

Such a utilization depends on the kind of material from which wastes are made, but primarily on the manner of their sedimentation. In the case of the precipitation method used until now in Poland, grain suspensions from zero + two mm in the initial chamber of the sedimentation basin practically eliminate such sediments from further utilization. However, controlling their sedimentation in such a way that the particular fractions of grains will be evolving separately, changes in a radical way the scope of their utilization.

Obtaining from these wastes, even if only the grain fraction is two to 0.5 mm, which is on the average 50-75 percent of the entire waste quantity, enables their utilization as standard sand for the building industry and for road building. The further evolvement of the dust fraction, composing 15-30 percent of the waste quantity, also enables its wide application in the industry. Depending on the kind of aggregate, this fraction can be utilized for various purposes. The dust wastes, made of a crushed basalt aggregate, can be used for ceramic building production, raising the resistance and refractoriness. Dust wastes from granite and natural aggregates are suitable for building material production, used as a dilution material. The wastes derived from crushing, for instance, the dolomites, serve as standard value components of cement clinker. The above named uses of some wastes applications are given only as examples.

The Possibilities of Limiting Devastated Areas by Constructed Sedimentation Basins

Entirely different problems and solutions for devastated areas holding sediment wastes already deposited, from the ones which will come into being in the future, will arise.

First, we have no influence now on the nature of waste sedimentation and in the decrease in the surfaces occupied by them. Our efforts will be limited mainly to the maximum possible economic utilization of them or at least to stack them into tall stacks or ultimately to reclaim them. The primary problem, however, of these activities is to desiccate the deposited wastes in the sedimentation basins with specific methods for each of the sedimentary sizes relevant to the local conditions of the sedimentation basin foundation. For instance, the recovery of regions occupied by the fluid or soft-plastic wastes of a postfloatation of sulphur depends on their capability to be piled up on a

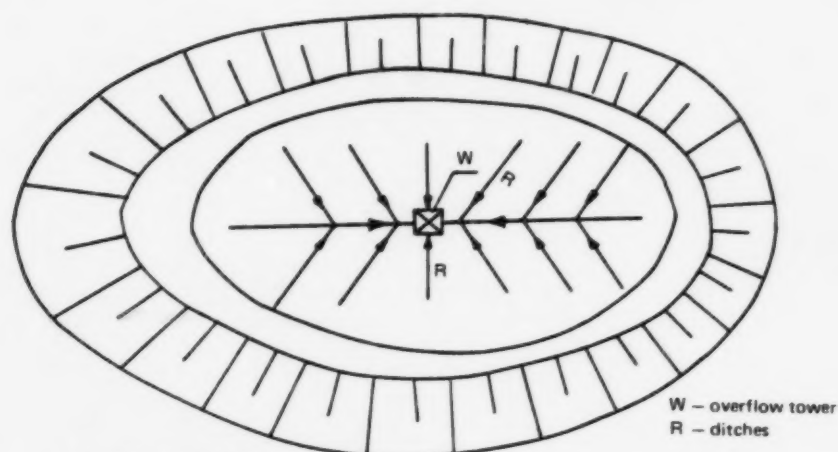
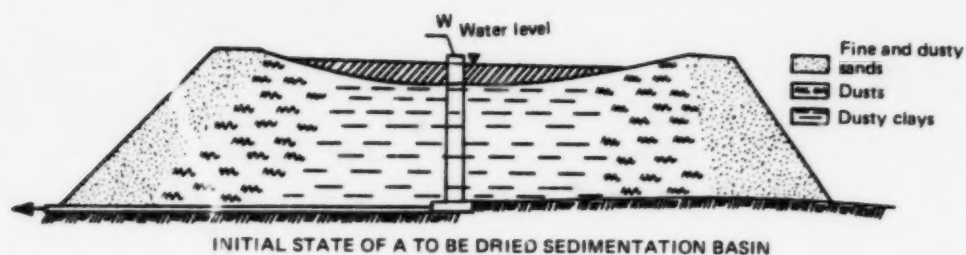
stack or to be utilized for agricultural purposes. In both cases their initial draining off to at least a plastic state is required, so that they can be worked with excavators and transported, for example, on conveyor belts and then piled up on a dry stack (Figure 4). This, for instance, is possible with electro-osmotic methods which are now being investigated in cooperation with E.P.A. Such wastes for agricultural purposes must, besides their initial draining, be brought to a state enabling their distribution onto the fields. For this purpose, they require further atmospheric drying through adequate stacking into heaps that should facilitate a gravitational outflow of precipitation water, with the simultaneous creation of intensive evaporation conditions (Figure 5a). Depending on local atmospheric conditions, the heaps can be piled only once, or formed and stacked many times. The cycle of drying may take a whole year or perhaps only a season. Prepared in this way, waste possessing 16-22 percent of water can be transported by lorries or a railroad and distributed on the fields with the use of normal agricultural machinery. Investigations are underway as to how to get rid of atmospheric drying (Figure 5b).

Strong drying substances are being added to the fluid or a soft-plastic waste, in order to obtain an optimal consistency for their transport and distribution on the fields and, also, these methods allow the achievement of a more advantageous composition of the prepared mixture. The drying components could, for instance, be fly ash, for their consistency also presents difficulties in their utilization. A combination of both types of wastes gives a mixture profitable for agriculture in both composition and consistency. Great efforts are being made presently regarding the limiting of areas of sedimentation basins through the use in the production process of an accelerated sedimentation of solids and then forcing their dewatering by centrifuges, presses, or the utilization of electrokinetic phenomena. Such methods, as yet, are comparatively inefficient, especially when it comes to pulp containing large quantities of clay suspensions. Nevertheless, this direction of research is considered as having a future, because it allows for a significant limitation of the occupied areas by basins.

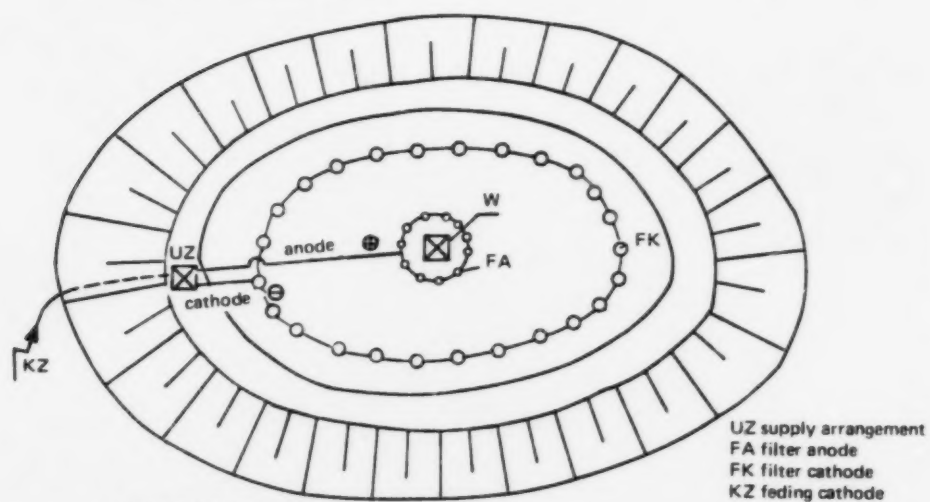
The quantity of wastes remains the same, though, and the problem of their storage still remains an open issue.

With respect to this, parallel investigations are being conducted regarding the possibilities of economically utilizing wastes. The up-to-date research shows that the sphere of waste utilization could be appreciably broadened, given proper control of the sedimentation process. The washed wastes, for example, of some suspensions contain large amounts of grains of the 2-.05 and .05-.002 granulations. Sedimenting such wastes in one sedimentation basin, even when dry, constitutes a useless waste. A considerable portion (sometimes 90 percent) of the wastes can be a building sand, or the dust used as a component in the production of building cement. A condition of their economic usefulness is the purposeful process control of the sedimentation, based on separate precipitations of sand, dust, and clay fractions.

Figure 6 shows, for example, one of the methods enabling the separate sedimentation of particular fractions. Such a preparation of wastes provides, in some cases, conditions for their economic utilization even up to 90 percent, thus creating opportunities for a gradual, proportional decrease in devastated cultivated areas.



I. PHASE OF DRYING
Evacuation of superficial and precipitation waters from the sedimentation basin



II. PHASE OF DRYING
Deep drying of the sedimentation basin with utilization of electrokinetic phenomena, to enable the sediment working with the excavators

Figure 4. Initial Drying Stage, Enabling a Working of Sediment With the Excavators.

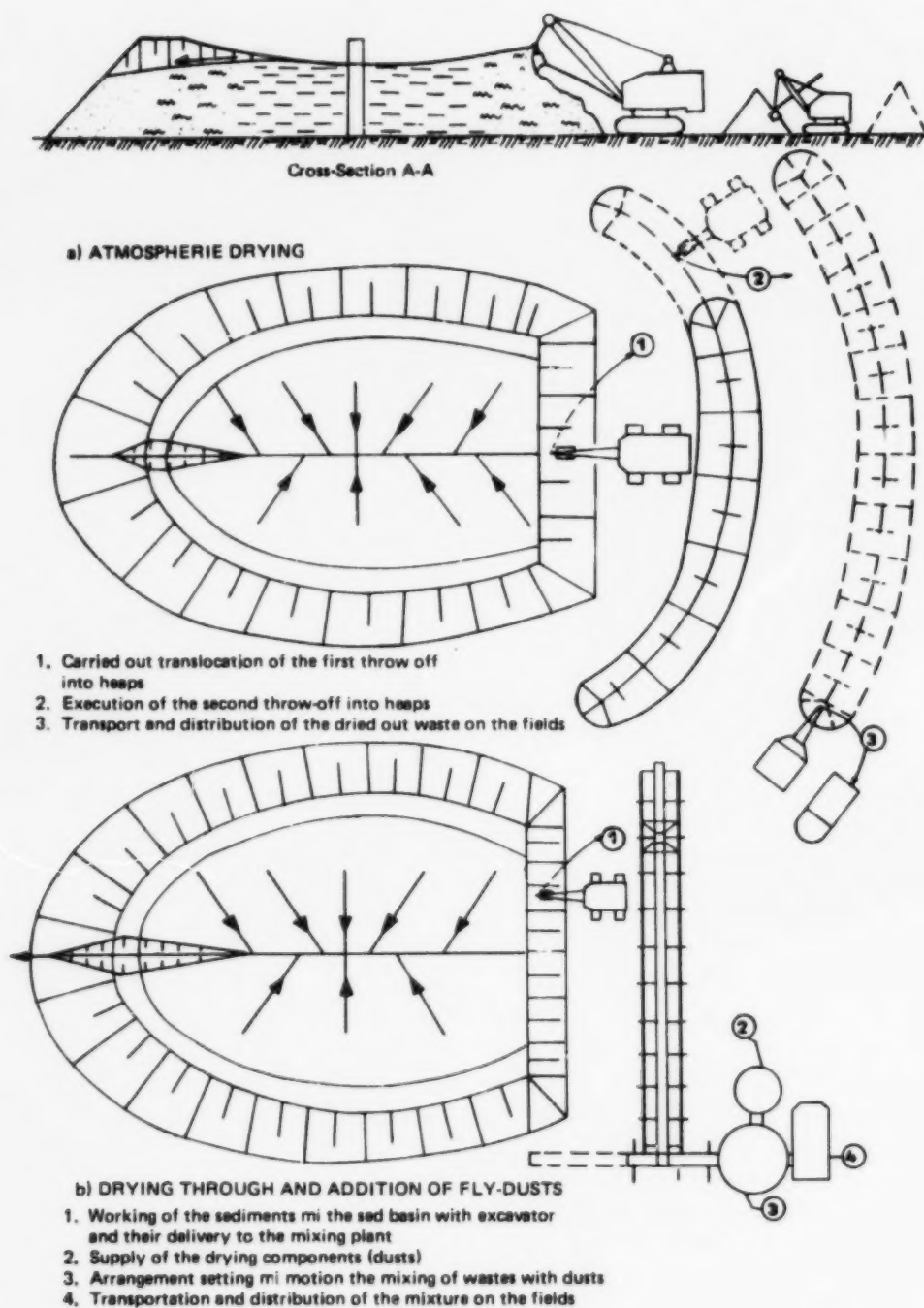
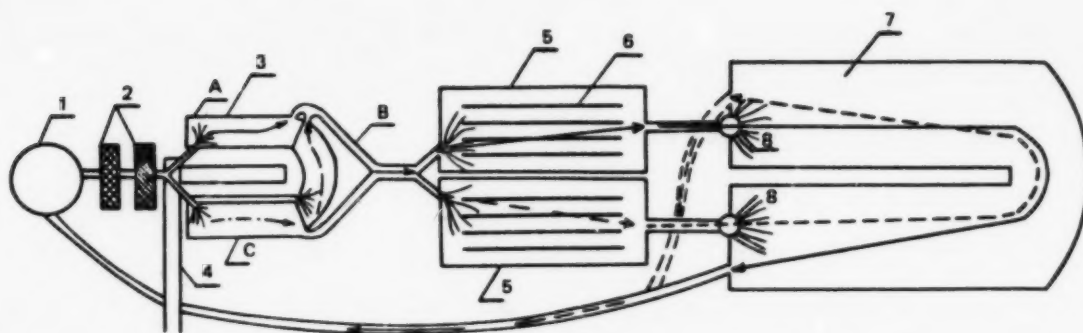


Figure 5. Phase of the Wastes Drying for Their Utilization for Agricultural Purposes.



1. Washing installations.
2. Sieve assemblies separating out gravel fractions from the wastes.
3. Three chambered sedimentation basins for sedimentation of sandy fraction in which during a filling of chamber-A, as an example, the chamber B is being dried, and the chamber C emptied.
4. Conveyor to transport the dried out sand onto the stack or to a consignee.
5. Sedimentation basin of a dusty fraction ($0.05 \div 0.002$ mm) in which during the filling of the chamber I, chamber II is dried and filled with.
6. Electro filters accelerating the drying of dusty sediments.
7. Clarifying basin to sedimentation of dusty fractions.
8. Installations dosing the speeding up the dusty fractions sedimentation.

Figure 6. A Diagrammatic Example of a Selective, After-Floatation Wastes Sedimentation.

Summary and Conclusions

Within the framework of a short report, there is hardly a chance to consider completely any of the issues discussed in it. Attempts were made only to draw attention to a few of the most essential elements, which, in the opinion of the author, postulate the possibility of limiting regions occupied by some fluid deposits, as well as the possibilities of maximizing their economic utilization.

Attention was focused on the existing two groups of problems connected with this issue:

1. Problems connected with the utilization of wastes already deposited in various kinds of sedimentation basins.
2. Problems connected with the utilization of wastes which will be produced in the future.

The method of composition of the first ones is beyond anyone's control now. We have to accept them as they are, do our best in testing their individual usefulness, and devise technical methods for their economic utilization. In the case of their uselessness, we would have to find out at least ways for reclaiming them in the future. The storage of liquid wastes should be controlled in a purposeful manner with the aim of either their economic utilization or their reclamation.

Such wastes ought to be neutralized, while still in a liquid state, should not harm the surroundings, and be stored in such a way as to occupy as little as possible usable land, and should not be a menace to the environment.

One does not expect, of course, to meet these requirements in every case.

For a number of cases, as this report indicates, such opportunities exist, however, to utilize these wastes in a proper manner at least in the deposition stages.

Electrokinetic Dewatering and Consolidation of Mine Mill Tailings

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Spokane Mining Research Center
U.S. Bureau of Mines

Introduction

Mill tailings, the waste from ore refining, are often used to backfill underground mine openings in cut-and-fill operations. This backfill provides structural support and a base upon which men and equipment can effectively work in subsequent mining. Tailings obtained as a watery slurry discharge from the mill circuit contain significant fractions of very fine grained materials and therefore dewater slowly and incompletely by natural drainage alone.

To improve drainage, tailings used for backfill are classified above ground, and the coarse fraction is hydraulically transported for underground placement. After placement, solids settle, surface water is decanted, and the residue dewatered further by natural drainage.

Classification removes sufficient fine particles (slimes) to provide settled fill that will be porous enough to dewater rapidly by natural percolation and result in good support material. The unusable slimes are placed above ground in ponds behind tailings dams where they remain watery and non-cohesive indefinitely. Tailings dams are costly to build and maintain and are ecologically troublesome. A shortage of backfill may also result from placing material above ground, thereby hampering mining operations.

Although classified, the material hydraulically placed underground still contains considerable quantities of fine-grained material. These fine particles do not settle out with the coarser "classified" grains, but remain in suspension and are carried along with the decanted water to collection sumps. There the slimes are usually thickened and then transferred into abandoned mine openings, impounded behind dams across unused tail drifts, etc. These slimes, however, never dewater and consolidate sufficiently by gravity settlement to form useful fill.

These problems suggest a need in the mining industry for an improved dewatering system for fine-grained material. Such a system could reduce or eliminate above ground tailings ponds, improve backfill density, beneficially use slimes collected in underground sumps, and provide more backfill. Such improvements also would enhance safety of men and equipment.

Preliminary investigation by the Bureau of Mines, Spokane Mining Research Center (SMRC), indicated that mill tailings, particularly fine particles, could be effectively dewatered by electro-osmosis. (Electro-osmosis, an

electrokinetic phenomenon, is the forced movement of water from one electrode to another in fine-grained soil by application of dc potential.) SMRC, therefore, initiated a research project to determine the practicality and economic feasibility of using electrokinetic techniques for dewatering and consolidating mine mill tailings.

In the first phase of this project, numerous small-scale laboratory tests were performed. Unclassified tailings from a single mine were placed in small plastic models (0.3 ft³) and electrokinetically dewatered and consolidated under a broad variety of application procedures and equipment arrangements. The results clearly demonstrated the effectiveness of electrokinetic treatment on these tailings, and findings were published in Report of Investigations (RI) 7892.

In the next step, the most effective procedures used in Phase I were applied to a large variety of types and classifications of tailings from the north Idaho mining district. Good response was achieved with all material tested, and results were published in RI 7900.

In the third phase, limited field tests were performed on unclassified tailings in 18-yd³ simulated stopes using five different application procedures. Results, which verified the lab tests and demonstrated the effectiveness of electrokinetics on a larger scale, were published in RI 8034.

With these positive achievements, full-scale field tests were conducted and are described in this paper. To make the discussion easier to follow, a few phenomena relative to electrokinetic procedures will first be described.

Capillary forces, which act to hold water in small pores of fine grained material, make drainage by natural gravity alone impossible. Electro-osmosis can be effective in dewatering such material because, in contrast to gravity, it supplies a dewatering force whose effectiveness is essentially independent of pore size. It is generally a superior dewatering system for soils with a predominant portion of particles less than 0.02 mm in diameter. Electro-osmosis may also be effective for draining coarser soils, depending on such soil properties as ion exchange capacity, zeta potential, and particle-size distribution, as well as electrolyte concentration in soil water.

Electro-osmotic dewatering is accomplished by applying a potential field between electrodes inserted in the soil. This causes positive ions to migrate toward the negative electrode (cathode), and these ions, concentrated in excess near the surface of the negatively charged soil particles, carry along the water filling the space between the particles.

Practical application of this concept includes collection and drainage provisions at or near the cathode (often a perforated metal pipe) from which water is removed by gravity flow or pumping. Alternatively, the cathode can be placed in coarse gravel or other easily drained soil.

Theories relating flow rate to such factors as the potential at the soil-water boundary where slippage occurs (zeta potential), water viscosity and dielectric constant, applied electric field, etc., have been developed for idealized flow in uniform capillaries. Quantitative prediction of dewatering rates in actual soils using any theoretical model is limited by the heterogeneous character of the soil, by the difficulty in obtaining reliable measurement of soil parameters, and most importantly, by accompanying processes (electrolysis, ion exchange, electrophoresis, etc.) that contribute to water transport and also change the nature of the soil. Therefore, it is essential to conduct actual tests on sample soils to determine feasibility, optimum potential, electrode spacing, etc.

It was consistently noted in our electrokinetic dewatering tests that even when free water at the anode is depleted, water continues to be discharged from the cathode. However, shortly after free water is depleted, cracks and fissures begin to form in material near the anode during electrokinetic treatment. These cracks are indicative of negative pore pressure, which causes consolidation. As treatment continues, the cracks become larger and gradually progress toward the cathode until electro-osmotic discharge ceases.

Electrophoresis is the electrokinetic phenomenon wherein small particles with electrical surface charges move through a stationary liquid due to applied electric potential. This is thought to have caused accelerated clarification of surface water in one of the field tests to be described.

Field Test No. 1

This test was performed off the 2000-foot level in a stope averaging 3 1/2 feet in width and extending 80 feet both east and west of raise 123. The stope was terminated on the east by a dead end and on the west by a timbered sandwall. A cross-sectional view of the stope is shown in Figure 1.

Backfill for stopes at the 2000-foot level and above comes directly from the ore concentration mill above ground. The tailings are classified to some extent by hydrocyclones at the mill, but still contain too much fine material. Additional fines are removed during placement by constantly adjusting the decant line to a height that allows time for the large particles to settle while the suspended fines are decanted with surface water and deposited in abandoned mine openings. Backfill for stopes below the 2000-foot level is further classified on the 2000-foot level before placement.

A three-electrode system was selected for this test. The bottom electrode, functioning both as a cathode and as a drain pipe, was iron pipe perforated to permit entry of drainage water and burlap wrapped to exclude entry of solids.

The pipe was placed on the stope floor and arranged to drain into the ore chutes. The middle electrode was a length of iron fence wire about 15 inches wide, supported by timber lagging 32 inches above the cathode. The upper electrode, similar to the middle electrode, was suspended near the ceiling ("back") using a nylon line and pulley arrangement, and was lowered to the fill surface only after settlement and decant were completed.

With this three-electrode system, fill area was divided into two zones: the zone between the upper and middle electrodes, and the zone between the middle and lower electrodes. This arrangement permitted individual treatment of each zone in terms of current density and treatment time. For example, the top zone was expected to contain all of the slimes and, therefore, would require more electrokinetic treatment than the lower zone, which was expected to contain only larger fill particles which drain well naturally.

The stope was filled in two steps. First, the stope was filled with slurry brought in through the vertical sandfill pipeline on the east end of the stope. However, because of inadequate caulking, water escaped through the sandwall, carrying with it most of the fine particles. After the surface water had disappeared, the fill was about as indicated by the heavy dashed line in Figure 1.

In the second fill step, slurry was brought in through a horizontal line on the west end of the stope. Open tees were installed to achieve better

distribution of fine particles. The stope was again filled to the top of the sandwall. After complete settlement of solids, surface water was decanted, leaving four large deposits of slime as shown in Figure 1. These deposits were soft and up to 16 inches deep, and walking on the surface was impossible. One step was all that could be taken, because extraction from 16 inches of this material required assistance. These slime deposits showed no indication of dewatering or hardening when left to settle by natural means, and as such, were considered desirable for electrokinetic treatment.

Three control samples were analyzed for physical properties. Sample 1 was taken from the slime deposit placed in the first fill step, sample 2 was taken from the discharge port nearest the sandwall, and sample 3 came from the port nearest the 123 raise. Physical properties of these samples are shown in Table 1, composition of material in Table 2, and grain-size analysis in Figure 2.

Table 1. Physical Properties of Tailings

Control sample No.	Cation exchange capacity, meq/100 g	Resistivity, ohm-cm at 21° C	pH, 21° C	Specific gravity
1	0.98		7.05	2.96
2	.42	2,715	7.00	2.92
3	.59	2,670	7.05	2.93

Table 2. Composition of Tailings

Control sample No.	Major Elements in Percent							
	Al	Fe	Si	Mg	Ca	Mn	Pb	Zn
1	0.74	8.58	55.8	0.61	0.94	0.69	0.48	1.05
2	.22	6.80	68.6	.55	.99	.66	.48	1.00
3	.16	6.36	67.9	.50	.82	.61	.47	1.03

Dc power was supplied by a solid state, 250-kW rectifier equipped with controls to set output voltage at any value from 80 to 475 volts. The upper electrode was lowered to the fill surface, and potential was applied to electrodes on both sides of the 123 raise. Dc application to the top two electrodes for 25 minutes was followed by 60 seconds of power-off. Power was then applied to the bottom two electrodes for 3.5 minutes, followed by 30 seconds of no power. This 30 minute cycle was repeated continuously during the test.

After 2.5 hours of treatment, the test was interrupted for inspection of the stope. Material had changed dramatically in that short time, having hardened and dewatered to the point where walking on the surface was easily accomplished,

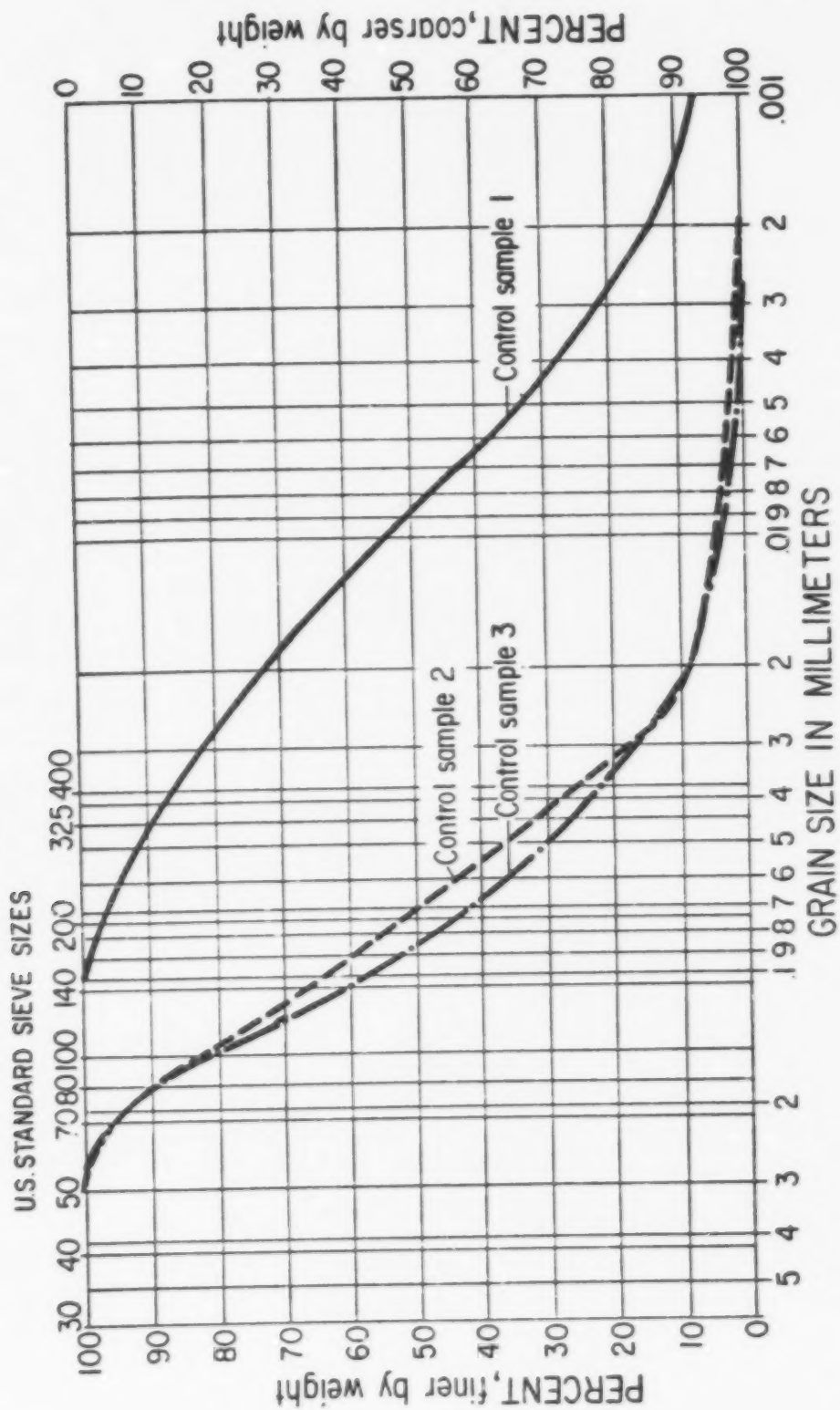


Figure 2. Grain Size Curves, Control Samples.

accomplished with soft spots noticeable only near the walls. Fifty kilowatt hours of power had been used. Treatment was continued with various power application rates and a number of interruptions, as indicated in Table 3, through the next 13 hours at which time fill surface was dry and firm throughout except for some soft regions near the walls. Total dc power expenditure at test end was 300 kW-hr.

Table 3. Power Application Data

Treatment period	Zone between Upper Two Electrodes			Zone Between Lower Two Electrodes		
	Applied volts	Current through fill, amp ¹	Current density, micro-amp/cm ²	Applied volts	Voltage gradient, volts/cm	Current, amp
6:30 pm-						
8:00 pm	325	55/10	211/38	350	4.6	49
8:00 pm-						
9:00 pm	300	51/9	196/35	350	4.6	49
9:30 pm-						
9:45 pm	300	51/9	196/35	350	4.6	49
11:10 pm-						
11:50 pm	325	55/10	211/38	350	4.6	49
11:50 pm-						
4:10 am	300	51/9	196/35	350	4.6	49
4:30 am-						
9:00 am	450	56/14	215/54	475	6.2	63
9:30 am-						
11:15 am	450	56/14	215/54	475	6.2	63

¹ Values to the left of the slash represent current flow into slope 123 west, and numbers to the right represent current into 123 east (see Figure 1).

Average dry weight moisture content and density of treated slimes, measured immediately after power shut-down, were 24.4 percent and 99.7 lb/ft³, respectively. Average moisture content and density of the coarser material were 17.8 percent and 89.1 lb/ft³.

Average surface hardness of the treated slimes was 475 psi and 125 psi for the coarser sand. Miners reported that the electrokinetically consolidated slimes provided a good working surface for mining operations and the coarse fill also was more firm than normal.

This test demonstrated that electrokinetics can be used underground in a safe and efficient manner. Dewatering and densification of settled slimes can be accomplished quickly and economically with modest consumption of electrical power. Procedures can be further modified and simplified to improve cost effectiveness.

The detailed report covering the July 1974 test is currently in editorial review.

Field Test No. 2

Old slimes were dewatered and hardened with electrokinetics in an October 1974 mine test.

A deposit that had been placed several months earlier behind a dam in an unused tailings drift on the 7500-foot level was selected. Material was very soft and 12 inches deep, and showed no tendency to drain or harden naturally.

No plans or provisions had been made to dewater this material before its placement. Consequently, there were no special drains or electrodes. As shown in Figure 3, existing car rails beneath the slimes were used as the bottom electrodes, and two 15-foot lengths of wire fencing, 30 inches wide, were placed on the slimes surface to serve as the top electrodes. Direct current was supplied by a 240-volt, 50-amp, dc, 12.5-kW generator driven by a 20-hp, ac motor.

The wire electrodes served as cathodes for the first 60 minutes of power application. This immediately brought to the surface considerable water that was routed over the dam in small ditches. Polarity was then reversed, and by automatic control the two wire electrodes alternately served as anodes for 30-minute intervals. (The small motor generator could not supply enough power to use both anodes simultaneously.) The two rails together served as cathodes throughout the test after the initial 60 minutes.

After 9 hours of treatment on each pair of electrodes, slimes had solidified and hardened appreciably. Surface hardness at the conclusion of the test ranged from 350 psi immediately beneath the fence wire to zero at the stope wall, with hardness exceeding 150 psi everywhere except within 1 foot of the stope wall. The material had consolidated sufficiently to permit removal from the mine by muckers, ore cars, and ore skips.

Dewatered material was not measured for density and moisture content, but the effectiveness was well demonstrated in that the material had consolidated sufficiently to permit removal from the mine by mucking machines, ore cars, and ore skips. Mine operators were enthusiastic about the results.

Field Test No. 3

A test in November 1974 determined whether slimes, transferred from a collection sump into a working stope, could be converted by electrokinetic treatment into competent material in a reasonable time with acceptable power consumption.

A working stope on the 7500-foot level of a metal mine was equipped with wire fence electrodes as shown in Figure 4. A water-tight sandwall was constructed, and the stope was filled with about 150 yd³ of thickened slimes transferred from a collection sump. Normally a considerable portion of the solids in this slurry remain suspended for days and even weeks. The first step of the treatment process was to hasten clarification with dc current flow through the slurry. As soon as the fill was completed, a floating wire-fence electrode was placed on the surface of the fill and dc power was applied through a 12.5-kW generator.

Current flow was adjusted to 55 amperes at 150 volts with negative potential applied to the floating electrode and positive potential to the bottom electrode. This procedure accelerates water clarification because the small particles that normally remain suspended for relatively long periods migrate

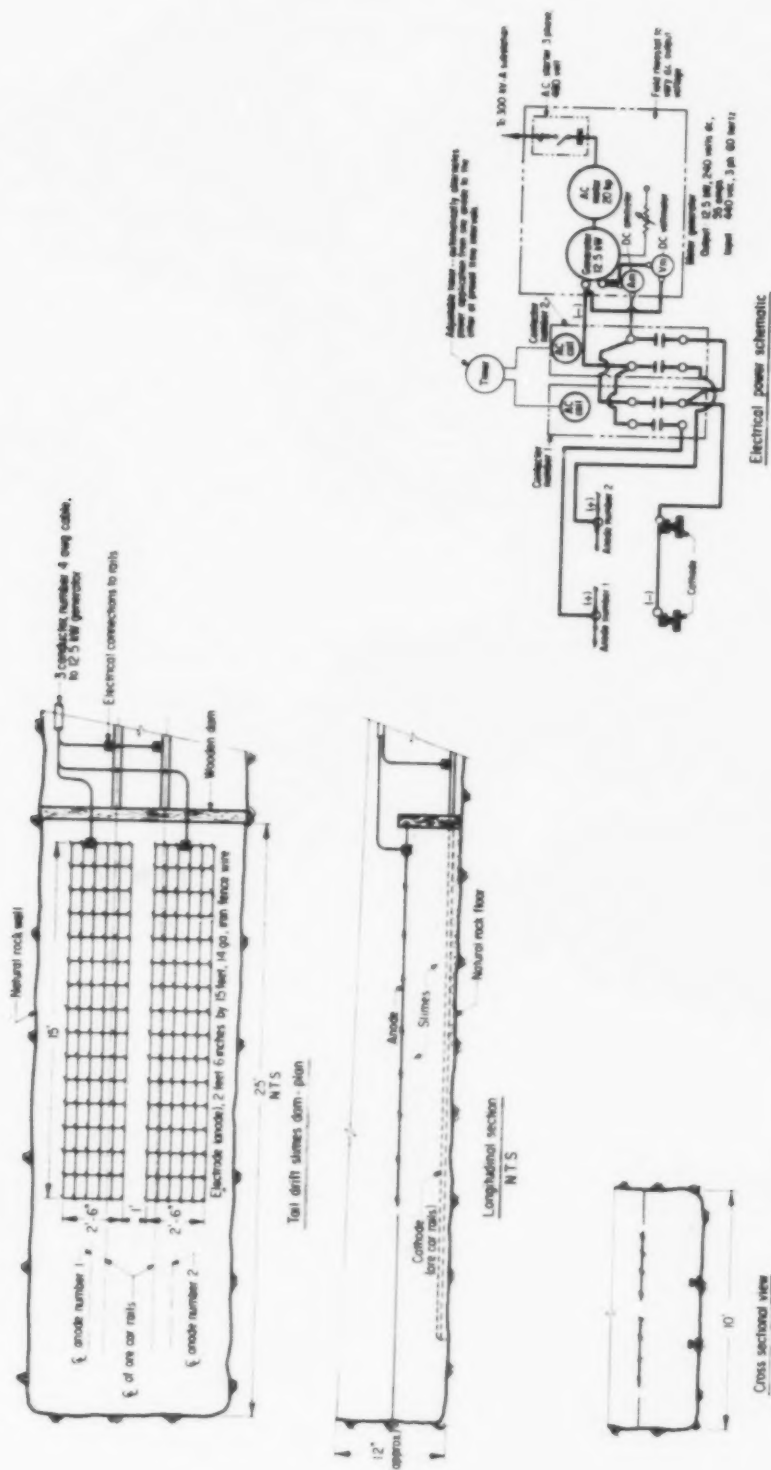


Figure 3. Layout Field Test No. 2.

downward from electrophoretic action. Almost all of the surface water, about 5,000 gallons, was clarified in 4½ hours while using 37 kWh of power. The clear water was drained off, and the floating electrode was removed.

On the following day, treatment of the soft, noncohesive residue was started. The 12.5-kW generator supplying the power had a maximum output of 60 amperes, limiting treatment to one 14-foot section at a time (Figure 4). Power (at about 150 volts and 55 amp) was first applied to the back section (anode 7) for 4 hours, and then to the second section from the front (anode 3) for the next 2 hours. Definite islands and shrinkage cracks formed during this 6-hour period.

Power was applied for 45 additional hours, for a total of 51 hours. Of the total treatment time, 25 hours and 210 kWh were used in the front section; 13 hours and 140 kWh in section 2; 10 hours and 110 kWh in section 3; and 4 hours and 30 kWh in the back section. The fill had consolidated to about 60 yd³ with a total power consumption of 8.2 kWh/yd³. Material in section 4 was soft, and surface hardness measurements were not made; however, hardness ranged from 0 to 40 psi in sections 2 and 3.

Best results were achieved in section 1, which had the longest treatment period. Hardness in this section ranged from 40 to 250 psi, with the hardest material under the anodes. Average dry weight moisture contents and densities of samples taken beneath the anode were 30.2 percent and 93.4 lb/ft³, respectively.

Field Test No. 4

Test 4 in January 1975 was a repeat of test 3 in another mine with some differences. The water clarification step was omitted because suspension of fine solids was not a severe problem. Also, availability of a larger generator (40 kW) permitted a simpler electrode system. Electrodes were lengths of 5-foot-wide iron fence wire. The cathode was placed on the stope floor, and the anode was supported 30 inches above the floor. After complete settlement of solids, surface water was decanted and the residue was electrokinetically treated. Although physical properties and composition of the 3,000 ft³ of slimes treated in this test differed somewhat from material used in test 3, results were quite similar. A report of procedures and results will be submitted for publication.

Field Test No. 5

In January 1975 electrokinetic treatment was applied to an old and large slime deposit impounded behind a dam in an unused tail drift on the 4000-foot level. The deposit, about 200 feet long by 10 feet wide by 5 feet deep, contained substantial mineral value, having been enriched while flowing to collection sumps in haulage areas where ore spillage occurs. The slimes were very soft and showed no tendency to dewater further by natural drainage.

Existing ore car rails on the floor of the tail drift were used as the cathode; fence wire laid on the surface served as anodes. A 40-kW generator furnished dc power at about 140 amp at 240 volts. Generator capacity limited treatment at any one time to 30 lineal feet (300 ft³). Power application drove the water to the surface from where it flowed via small ditches over the end of the dam.

After treating three 30-foot sections for 3 days each, using about 35 kWh of power/yd³, the material had hardened sufficiently to permit handling with mucking machines and ore cars. The material was removed from the mine with ore skips and processed for mineral recovery. This test successfully demonstrated an effective and practical procedure for removing slimes from a deep mine. A full report will be published.

Conclusion

Although our work so far has been limited to one general mining area, results show that electrokinetic treatment will effectively dewater and consolidate mill tailings at a reasonable cost. At least one and perhaps two mines are preparing to use this process in dewatering and densifying slimes as part of their regular operation. Because of our positive results, another large mine, outside the United States, is currently conducting research to evaluate effectiveness of the process in its mining operation.

Our future plans include continued research toward effectively and economically placing all mill tailings underground in mines that use hydraulic backfill. Emphasis will be on more effective application procedures, improved rheology and use of additives.

Specifications are being prepared for contract research to identify and evaluate hazards associated with underground use of this process and to develop procedures to minimize or eliminate them. Contract results will be used in developing safety standards.

This paper has been limited to minimal discussion of our work, but full details on procedures and results will be available in published Bureau reports.

RECLAMATION OF FILLING SAND OPEN PITS AFTER EXPLOITATION

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Introduction

After lignite openpit mining, the biggest devastation on the surface of the land in Poland is caused by the exploitation of filling sand, required for the needs of underground mining.

The phenomenon of surface deformation confronts hard coal underground mining with two alternatives:

1. Limitation of exploitation only to those deposits located under a surface not built upon, and conducting the exploitation with the so-called "fall of roof" method.
2. Exploitation of deposits also situated under a permanently built upon surface with a simultaneous application of liquid fill, which secures the surface against a subsidence. This application is based upon loose material introduced by means of a hydrotransport to replace the mined out mineral. The most suitable material for this purpose is a sand of an average grain size, without any contaminations with organic or floating matter.

Liquid filling was first used in Polish territory by the end of the XIX century, and from this time onwards, the waste lands in a form of abandoned sand excavations became a problem. Presently, about 40 percent of the entire hard coal exploitation in Poland is connected with an application of the liquid fill. The yearly use of sand for this purpose comes to 43 mil. m³, and this occupies a surface of about 300 ha. Despite the tendency to a wider use of aggregate derived from the mines, the use of sand grows continuously. As a result of mining activity, waste lands have grown and are increasing in the form of temporarily uncultivated mined out sand pits and also dry soils located on the peripheries of the excavations within reach of the cone of depression. By 1939, the area of waste lands formed as a result of filling sand exploitation amounted to 1,500 ha. By the end of 1974, the total area of the exploited pits of filling sand covered about 7,000 ha.

In perspective to the year 1980, however, one anticipates the exploitation of sand on an area of about 20,000 ha.

The above magnitudes indicate how important the issue is of reclaiming these terrains.

Characterization of the Overburden Soils

The exploitation of filling sand proceeds, as a rule, on sandy soils that are poor in humus content. Such terrains are often covered by pine forests.

In such a situation the overburden does not possess a greater value. This is a soil that is little active microbiologically.

A very small content of elementary nutrient components was ascertained, as: P_2O_5 - 0.02 - 0.03 percent, K_2O - 0.2 - 0.4 percent, N-only traces established, $CaCO_3$ - 0.003 - 0.005 percent. The reaction on the whole is neutral, pH in H_2O shapes itself from 6.5 - 6.6.

If, in this case, the thickness of the humus layer (top soil) does not exceed 30 cm, then it is exploited together with the sand, but if it is greater than 30 cm, then it is stripped separately with the aid of bulldozers.

Such an overburden is displaced from heaps and thrown onto the exploited terrains with the aid of diggers. When, however, the exploitation of sand takes place on areas previously occupied by agricultural cultivations, then we must deal with a thick layer of humus soil in overburden, reaching often 0.5 meters in depth. This is largely a soil rich in elementary nutrient components. Such soil, as a valuable material for reclaiming applications, is scooped with the aid of bulldozers, thrown with excavators on the exploited terrains and hauled with wagons on normal gauge tracks to the terrains assigned for reclamation.

The Technology of Filling Sands Extraction

The beginning of filling exploitation is commenced by preparatory work. When the regions are forest lands, then deforestation follows these terrains and the uprooting of trunks. After cutting down the trees and uprooting the trunks, clearing the sand roof from bushes, branches, small stumps and roots follows. After clearing the deposit's roof, the cutting open of the deposit follows by means of excavators with a capacity to 600 m^3/hr . The winning during this stage of operation is heaped on a spoil, which, in turn, on its next haulage is loaded onto the wagons and carried off to the consignee. After cutting open the deposit, a ditch is dug out to carry the water away outside of the strip mine. Arterial (stable) and productive, slidable tracks are laid, where drafts of cars are placed against excavators that work the sand from the slopes, and the cars (wagons) are loaded on it with the aid of belt conveyers.

Considering the bulk of the work connected with the excavation of the sand, we distinguish the following exploitation systems:

- A one side exploitation (one wing) is characterized by a general progression of the working front, commencing on one of the deposit boundaries and finishing at the other;
- A two sides exploitation system, where the general tendency of the working front progress is from the center to the boundaries of the deposit;
- A selective exploitation is being characterized by the excavation of a deposit in a manner that permits one to sort out various kinds of the deposit excavated on one face;
- A parallel exploitation system, based on the uniform shifting of the working levels, where an amount of elementary displacements of the working face along the entire-level length are approximately equal;

- A fanlike system of exploitation based on a varying augment in the shifts of face along the level--as it recedes from the point of the working level turn. A fanlike system is very often employed in the mines of filling sand, owing to the accommodating system of approach tracks to the excavators;
- A combined system of extraction, consisting of excavating the deposit from working levels of open pits, partly parallel and partly fanlike system of exploitation.

The exploitation of sand is being carried out with bucket wheel excavators (and in sporadic cases with shovel machines) with a capacity of from 500-1,000 m³/hr. The height of the exploited faces fluctuates from 9 to 12 m.

Condition of the Bed Abandoned After the Exploitation of the Filling Sand Ends

The exploited excavation of filling sand represents in relation to its surrounding a depressed surface. Such a depression in relation to the original level depends on the thickness of the deposit and on the technical possibilities of its exploitation in specified mining-geological conditions. Practically, this depression reaches 10-50 m in depth.

The terrain in a horizontal projection depicts an area intersected with heaps, formed fanlike or radially in relation to the point of turning (commencement of exploitation). The heaps left behind hold back the water, not allowing it to flow freely in the direction of the decline of the workings which, as a rule, operate with a 0.3 - 0.8 percent decline. Such waters stagnate and fill the depressions in the terrain. Solid, barren sand of fluvioglacial origin usually constitutes the floor of the excavation with a very small content of dust particles, which on the whole does not exceed five percent. The sand left on the bottom of the excavation normally possesses a thickness of 0.5 to 30 m, and is underlain by various formations.

The reaction of the parental soil in the floor of the workings before reclamation treatment is slightly acidic. The depth of the ground water table occurrence varies and fluctuates within 0.1 - 3.0 m. The microbiological analysis of the samples taken from the working's floor right behind the exploitation front indicated that in this soil almost no microorganism exists. Such material is also devoid of organic origin elements. Before the reclamation treatments can start, the terrain of the working must be suitably shaped and dewatered.

Classification of Abandoned Sand Pits

In order to improve the planning of reclamation works of the sand pits, a necessity arose to elaborate their classification.

The classification of the extracted sand excavation was made taking into consideration both the natural characteristics of the environment and the preparation of the floor for reclamation applications.

For the basis of this classification was taken here:

- The kind of formations deposited in the floor of the working and their resourcefulness;
- The after-exploitation water conditions and the terrain configuration arrangement, also the possibility of their improvement by way of water conditions amelioration and a mechanical levelling of the surface.

On the basis of the quality of the deposited formations in the floor and on the water conditions, a division was made into four categories:

- I. Ozotrophic habitats - very poor
- II. Oligotrophic habitats - poor
- III. Mezotrophic habitats - medium rich
- IV. Eutrophic habitats - rich.

These categories can occur in three degrees of humidity, on which is based a joint characterization of water and microclimatic conditions and also the influence of the micro-sculpture of the earth's surface exerted on them.

- A: the top layer-very dry, or dry
- B: the top layer of average humid, or humid
- C: the top layer-soggy, wet.

Classification of the Reclamation Process

To determine the problems connected with the reclamation of previously exploited terrains of filling sand, and to standardize the designations, the following classification was adopted.

The entire procedure of reclamation was divided into three stages:

- I. Prereclamation stage
- II. Reclamation stage, which can be subdivided into three phases:
 - a) the technical phase
 - b) the biological-preparatory phase
 - c) the biological realization phase
- III. The postreclamation stage.

The first stage comprises the investigation and elaboration of documentation and securing the valuable soil material required for fertilization.

The second stage (phase a) embraces the shaping of the excavation floor's micro-sculpture and the control of water conditions through a network made of ditches draining the workings and also the access roads and building.

The second stage (phase b) contains mineral and organic fertilization, mechanical cultivation, selection, and sowing of a papilionaceous and protective vegetation and a biological consolidation of the excavation slopes through planting of trees.

The second stage (phase c)--a biological realization--includes the maintenance and renewal of ameliorating arrangements, and the afforestation and supplementation of afforestations, and also nursing of cultures.

The third stage--the postrecultivation stage--comprises applications and treatments suitable for a given habitat, which will speed up the process of soil formation, protection from any erosion, and the adaptation of terrain to future economic plans.

On the basis of the classifications, the initial biological cultivation can be justified economically, through the introduction of a perennial papilionaceous vegetation, adequately adapted to the class and to the terrain's humidity level.

This, however, requires corresponding cultivation and fertilization applications, different for the particular categories and for the excavation's humidity level. For this purpose, thorough guiding principles are being elaborated, which after ratification by local authorities become the basis for the operation's accomplishment.

The Technical and Biotechnical Reproduction of the Excavated Pits' Floor Soils

The attempted reclamation of the mined out workings date back to 1929, when for the first time in Poland the afforestations of abandoned pits after exploitation were made.

Up to 1961, reclamation practices were performed in various ways, depending on the materials which a given company had at its disposal.

The employed reclamation methods of the exhausted sand pits did not have any scientific foundations, and their usability was different depending on the local conditions and the goodwill of a given company.

In these years 1961-1962, a furrow method (i.e. technical method) of reclamation was used. This method relied on a leveling out of the working's floor, and on putting on humic soil in quantities of 400-750 t/ha. The soil was placed in grooves to a depth of 40 cm, and a width of 50-60 cm, made at intervals of 1.4 m. Prepared in this way, the terrain was then afforested.

In some cases, before planting the trees, the one yearly lupine was sown plus such grasses as English bluegrass, orchard grass, timothy grass, smooth brome grass, and others and also some of the papilionaceous plants.

Between 1963-1964, this method of reclamation was slightly changed for a so-called biological method. The reclamation treatments were better adapted to the existing natural characteristics of a determined habitat. In comparison to the previous methods, the following changes were introduced:

- Greater attention was given to the shaping of the excavation floor, so that the ground water table stayed at a depth of 0.4 - 1.0 m. depending on the kind of soil.
- The delivery of humus soil was limited from 50-300 t/ha depending on the kind of organic matter.
- Sowing of grasses was limited to only sowing on the slopes of the draining ditches.
- The quantity of papilionaceous vegetation sown under the cover of annual lupine was increased.
- Excess water was carried away by means of a network of open ditches, situated in such a way that the terrain would not dry up.
- An autumnal ploughing of the working's floor was introduced, after previously levelling it; such a technique improves considerably the structure of the floor, especially one composed of clay.
- In order to fertilize loose sand, bentonite was being introduced, which takes the place of an organic material.

The results of furrow reclamation and the modernized (biological) method are various, in terms of natural and economical aspects. On the area reclaimed with the furrow method, sproutings of grasses and papilionaceous plants were observed on the belts being fertilized with humus soil. On the inter-rows, agricultural cultivations succeeded only in places where the ground water table was shallow (namely about 50 cm or less).

Excessive drying of the excavation negatively influenced the development and the success of the papilionaceous vegetation, and of the arborescent. Grasses such as orchard grass, timothy grass, smooth brome grass, ryegrass, and others during the period of dry weather worsened the water conditions to such an extent that the trees dried up in masses or only feebly vegetated.

The furrow method of reclamation was labor consuming and costly (about 120 thousand of zł. per. ha), owing to the deliveries of large amounts of humic soil (400-750 t/ha).

The modernized (biological) method of exploited sand pit floors reclamation has been shown to be more successful due to better papilionaceous and arborescent vegetation development, and also due to diminished costs by some 50-60 percent. This method was based on the natural classification of the old pits. For each of the categories of pits, detailed recommendations were given concerning the manner of reclamation, and these recommendations--to a large degree--improved the success of the cultivations. So now, after technical preparation of the excavation floor, its biological animation and soil processes formation are based on the introduction into the habitat of papilionaceous plants of such quantities and species that their root system should present no competition to the arborescent vegetation in a damaging extent, in providing the latter with water. (See Table 1).

An organic fertilization with peat or with a forest humus soil, in quantities of 50-100 t/ha, is being used in environments having dry, loose sands.

The supplied organic material, in complement with a full mineral fertilizer (NPK) after a thorough mixing with a disc harrow with sand, produces a medium which suits the sprouting and growth of papilionaceous vegetation and, subsequently, arborescent vegetation.

The Planting of Trees

As a result of the employed reclamation treatments which contain the reproduction of soils with technical methods, agrotechnical cultivations, NPK mineral fertilization, and precrop cultivations of papilionaceous plants, one can prepare the terrain for future afforestation.

An area prepared in such a way can be afforested with suitable species of trees and bushes (See Table 2). Such afforestations are being made with two-year-old seedlings of first class with a well developed root system, at distances one x one m.

The development and growth of trees in such conditions is similar to normal forest cultivations. The amount of annual increments depends on the environment and on the sort of trees. On the average, it forms itself on the basis of 20-110 cm rates.

The afforestations of terrains of completed exploitations in the industrial regions are made with deciduous species, which show greater immunity to smoke.

Conclusion

The gathered experiments have indicated that reclamation of open pits after completed exploitations of filling sand is possible through a:

- Proper formation of the terrain sculpture and water conditions;
- Reproduction of soils with technical methods;
- Employment of suitable agrotechnical methods.

In the region of Gornoslaski (Upper Silesian) Industrial Territory where the greatest number of these kind of sand pits exist, forest restoration is the main focus of reclamation.

This tendency is justified in this region where there is one inhabitant for every 0.08 ha of forest, whereas the country's average in this respect is 0.26 ha.

Table 1. Composition of the Mixtures of Papilionaceous Plants Used as Reclamation Treatments on the Exploited Out Sand Pits

Stand	Category I	kg/ha	Category II	kg/ha	Category III	kg/ha	Category IV	kg/ha
Dry	These stands must be irrigated and go over in to the humid ones							
	Blue lupine (<i>Lupinus angustifolius</i>)	180	Blue lupine (<i>Lupinus angustifolius</i>)	200	Blue lupine (<i>Lupinus angustifolius</i>)	200		
	White melilot (<i>Medicago albus</i>)	15	Sundial lupine (<i>Lupinus polyphyllus</i>)	10	Sundial lupine (<i>Lupinus polyphyllus</i>)	10	No dry stand	
	Sundial lupine (<i>Lupinus polyphyllus</i>)	10	White melilot (<i>Medicago albus</i>)	15	Birdsfoot trefoil (<i>Lotus corniculatus</i>)	10	occurs	
	Birdsfoot trefoil (<i>Lotus corniculatus</i>)	8	White clover (<i>Trifolium repens</i>)	3	White melilot (<i>Medicago albus</i>)	5	in this category	
Humid	White clover (<i>Trifolium repens</i>)	5	Lucerne (<i>Medicago lupulina</i>)	3	White clover (<i>Trifolium repens</i>)	5		
	Anthyllis (<i>Anthyllis vulneraria</i>)	3						
			Blue lupine (<i>Lupinus angustifolius</i>)	180	Blue lupine (<i>Lupinus angustifolius</i>)	180	Blue lupine (<i>Lupinus angustifolius</i>)	150
			Sundial lupine (<i>Lupinus polyphyllus</i>)	15	Sundial lupine (<i>Lupinus polyphyllus</i>)	10	Sundial lupine (<i>Lupinus polyphyllus</i>)	15
			White melilot (<i>Medicago albus</i>)	10	White melilot (<i>Medicago albus</i>)	7	Birdsfoot trefoil (<i>Lotus corniculatus</i>)	10
Wet			Birdsfoot trefoil (<i>Lotus corniculatus</i>)	8	Birdsfoot trefoil (<i>Lotus corniculatus</i>)	10	White clover (<i>Trifolium repens</i>)	5
			White clover (<i>Trifolium repens</i>)	5	White clover (<i>Trifolium repens</i>)	6	White melilot (<i>Medicago albus</i>)	2
			Lucerne (<i>Medicago lupulina</i>)	3	Lucerne (<i>Medicago lupulina</i>)	4	White clover (<i>Trifolium repens</i>)	5

Wet stands must be adequately ameliorated and pass into humid stands

The main purpose for reclamation is the formation of green terrains necessary for recreation and rest areas. For this reason, the production of timber is not the deciding factor here.

Beside forest cultivation, one also carries out water reclamation in this region. The task is to create water reservoirs where a sufficient amount of water occurs for filling and exchange during its exploitation. Such reservoirs have many assignments. They store the water required for communal or industrial purposes, and are used as recreation and sport centers (sailing, canoeing, etc.).

To a small extent, agricultural reclamation is also carried out here especially in the neighborhood of dwelling settlements, where conditions exist to establish small garden plots used by people living in big blocks.